CCM
CONSEJO DE COMPETENCIAS MINERAS

NEW TECHNOLOGIES AND THEIR IMPACT
on the Competencies Required by the Mining Industry

The present report has been elaborated by the Consejo de Competencias Mineras, an initiative hosted by Consejo Minero and supported by the expert advice from Fundación Chile.

Consejo Minero team
Verónica Fincheira H., CCM Manager
Sofía Moreno C., Commissions and International Affairs Manager; former CCM Manager.
José Tomás Morel L., Studies Manager.
Christel Lindhorst F., Communications Manager.
María Paz Baghetti O., former Head of Communications Projects.

Fundación Chile Team
Hernán Araneda D., Center for Human Development Manager.
Diego Richard M., former Director Sectoral Initiative Program.
Philip Wood V., Director Human Capital and Productivity.
Gabriel Rojas L., former Director of Studies.
Verónica Cid, Head of Studies.

Editing, design & layout
Alder Comunicaciones

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NEW TECHNOLOGIES AND THEIR IMPACT
on the Competencies Required by the Mining Industry


PRIMERA LIMPIA
ESPESADORES
SEGUNDA LIMPIA
Pila de Agua de Proceso
Pila de Cabeza Agua de Proceso

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The technological transformation is a key issue for the mining industry. In recent times, mining companies have embraced the different technologies available and integrated them into their current operations and projects, exploring diverse initiatives and thus unfold the potential inherent to the fourth industrial revolution.

Technology has served as a complement for workers and has allowed different industries to perform their activities in a more efficient and productive manner.

The Skills Council for Mining Competencies (CCM) promotes the development and incorporation of new competencies for mining workers, upgrading knowledge and managing their transition into digitalized mining, accompanied by a strategy of human capital development that supports a workforce resilient enough to adapt to changing scenarios and with more competitive sustainable results.

This study is intended to provide an insight into the needs posed by the mining sector in Chile and, based on those observations, prepare and drive the required changes leading to a formation process aligned to this industry. From its very beginning, the work defined by the CCM has applied this same approach, defining gaps and tendencies to draw a line of work as a formative response that is adequate, both in quality and time.

While this study is aimed at linking the main technological changes and assessing how these impact the work competencies, one of the main challenges it poses on us is figuring out how to develop plans to reconvert the competencies currently owned by mining workers and help them into adopting new technologies.

We want to thank everyone who participated in this study, our partners companies for providing information and sharing their experience in the preparation of this document intended to promote and enhance the collaboration between the world of formation and sectoral companies.

Verónica Fincheira
Consejo de Competencias Mineras Manager

The impact the so called industrial revolution 4.0 is expected to have on jobs has sparked a growing interest. The transformation and eventual loss of employments and occupations as we know them today, raises reasonable concern, all the more if we consider that an important segment of Chilean workers perform routine jobs, susceptible to being replaced by technology.

In terms of large-scale mining, the arrival of digital technologies (big data, artificial intelligence, internet of things, among others) represents an opportunity not only to improve productivity but also to upgrade safety conditions for workers engaged in operational areas. The creation of integrated operations centers, interoperability and the availability of increasing volumes of data open a chance to step into the so called smart mining, examples of which can be seen in countries like Australia and interesting advances in Chile.

In this context, the present study is a first approach into understanding the repercussions these changes will have on the skills, knowledge, and competencies to be required from the workforce in the main value chain of the mining business (Extraction, Processing, and Maintenance).

This study focuses on the main technological changes to be experienced by each productive process and the celerity of their occurrence. It also analyzes the extent to which these changes will translate into requirements of new skills and human knowledge to complement the incoming technologies. All the above with the purpose of understanding the scale of the efforts required to upgrade and advance the work competencies as well as the convenience to intensify the efforts the CCM has been deploying since 2012 to communicate the formative world the new skills, knowledge, and competencies the mining industry will be requiring in the coming years.

I would like to thank all the companies and professionals working in the CCM who provided important information and were willing to share decades of operational experience and prospective visions about the opportunities being opened by digital transformation for future mining workers and industry.

Hernán Araneda
Center for Human Development Manager, Fundación Chile

INTRODUCTION

OBJECTIVES

This study is aimed at estimating the extent of use of current and emerging technologies in the different positions existing in the main value chain (MVC) of large-scale copper (Cu) mining, with special focus on obsolescence, creation or change in competency requirements. At the same time, this study will evaluate the potential of development these new technologies have in the different mining processes.

To this end, the following specific objectives have been defined:

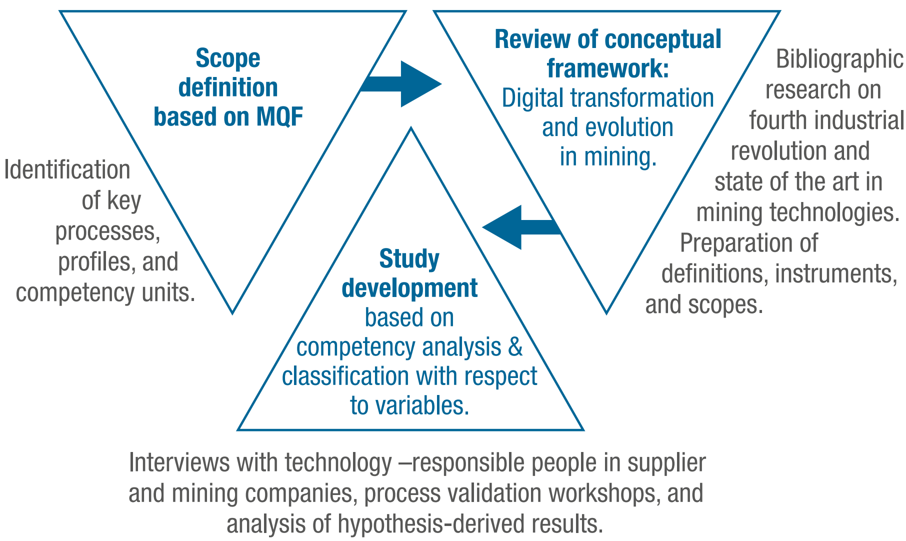
- Set a limited analysis scope of the processes, profiles, and competencies applied in the large-scale Cu mining by using the Mining Qualifications Framework (MQF) as a basis.

- Set an analysis framework associated to digital transformation and technological evolution with the purpose of determining the instruments and variables that will help classify all MQF-defined work competencies.

- Identify the technologies currently used in the mining industry as well as those that might be implemented in a 5-year horizon, defining their change potential, replacement, adjustments, and creation of work competencies, according to the cross-check between the MQF and the technologies identified.

STRATEGY AND WORK METHODOLOGY

In order to achieve the above objectives, the work methodology considered the following phases:



These stages include the following actions:

1 Identification of key processes, their profiles, and associated competency units

In this stage, the Mining Qualifications Framework and Work Competency Units (WCU) were used as the basis for analysis. The MQF establishes the main processes, and associated subprocesses, applied in mining tasks. Thus, the **Extraction** process scope includes the open-pit extraction, underground extraction, and blasting subprocesses. In **Processing**, the oxide, sulfide, smelting, and refining subprocesses were involved while **Maintenance** included mechanical and electrical-instrumental Maintenance.

2 Definition of theoretical framework and elaboration of analysis variables

A theoretical framework was set up based on a key concept: the fourth industrial revolution by Klaus Schwab, founder of the World Economic Forum. This, after considering the evolution of the processes historically known as “industrial revolutions”. Thus, the first of these phenomena in record is recognized by the introduction of water and steam-powered mechanical machines into the productive chain. The second industrial revolution marked its arrival by the mass production, the division of labor, and the use of electric power. The third event was characterized by the advent of electronics and information technology up to our present scenario known as the fourth industrial revolution where the use of cyber-physical systems, artificial intelligence, the internet of things and big data are its main players.

Three sources of analysis were established with a view to projecting how this evolution would affect mining processes. These sources considered a review of the technological state of the art in mining, interviews with technology leaders in the industry, and technical roundtables per process. Digital transformation and its impact on productive functions (how permeated these are by technology) were the first analysis variables applied. Secondly, the technological evolution proper; that is, whether or not these technological solutions are used in the execution of the mining processes selected.

3 Review of technological state of the art in mining

A data survey was conducted to find out about the main technologies employed in the ten identified subprocesses. To get a better understanding, this survey was focused on two moments in time: the technologies being used when the survey was carried out (2018) and a projection for the next 5 years.

4 Interviews with technology leaders in the mining industry

26 interviews were made with people responsible for managing and developing technologies in the main mine operations of our country as well as with important mining equipment and solution suppliers. People were asked about mine site processes, technologies currently in use and expected to be used, competencies under the MQF, and their 5-year vision on how they thought the panorama would evolve.

5 Technical roundtables per process

This activity was basically aimed at identifying, based on expert judgment, the impact of technological change on MQF competencies in Chile, in terms of digital transformation and technological level.

FRONTIERS OF STUDY

Mining Qualifications Framework

As for profile analysis -set up as an objective within this study- the Mining Qualifications Framework (MQF) was applied.

The above framework provides not only an orderly array of key processes, work profiles, and critical functions but also the relevant training requirements to develop each one of them.

It must be noted that constructing the MQF required consensual and collaborative work from 4 associations, 14 mining companies, and 2 suppliers and members of the Consejo de Competencias Mineras (CCM) with the expert advice from Fundación Chile. Thus, the information collected comes from different domains of mining activity.

Below is a description, characteristics and main components of the MQF to ensure a better understanding of this study.

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Description of MQF

MQF is a tool enabling the organization and classification, in progressive levels, of the learning results required by a person/worker to achieve a competent performance in an organization, industry, region, or country.

While the MQF was being constructed, the processes contained in the industry's main value chain, such as Extraction, Processing, and Maintenance and their related profiles and competencies, the qualification level arrangement, the identification of progression pathways among them, and the definition of qualifications were analyzed

The resulting qualifications constitute learning outcomes based on competencies that can be jointly developed and lead to work opportunities in the industry. A general descriptor was elaborated for each qualification which provides basic information for institutions providing education services for the industry.

The MQF has been drawn up on the basis of the Australian Qualifications Framework. The resulting product was a framework with five qualification levels providing technical training and covering from the formation of entry jobs to the formation of specialized technicians.

Over 300 representatives from the mining sector took part in the preparation of the Mining Qualifications Framework who contributed their knowledge and experience gained in their areas and processes.

MQF and its components

The MQF has been organized into three main processes: Extraction; copper, gold, & silver Processing, and Maintenance.

In turn, each process contains a number of subprocesses. For instance, Extraction involves subprocesses of exploration & drilling, open-pit extraction, underground extraction, and blasting. Processing comprises hydrometallurgy, concentrate, smelting, and refining subprocesses. Maintenance includes mechanical Maintenance and electrical-instrumental subprocesses.

All in all, the MQF contains a total of 175 profiles, 308 competencies, 99 qualifications, and 13 educational pathways.

Scope of the Study

In order to define the influence the new technologies will have on mining jobs, it was agreed that 3 processes, 9 subprocesses, 76 profiles, and 265 competencies would be considered in this study.

The **Extraction** process takes place in the first stage of the production cycle. It is executed once a new ore reserve has been fitted out as a productive mine site. Two types of ore extraction are distinguished: open pit and underground, depending on where the ore deposit is located and the characteristics of the rock hosting the mineral. In both cases blasting techniques are applied in the production sites and special zones are prepared for the circulation of haulage and loading equipment that will move the material to the next step of the production process.

The following are the subprocesses and their most representative competencies:

a) Open-pit extraction:

- Operate high-tonnage truck.
- Load ore with shovels.
- Conduct open-pit drillings.
- Coordinate mine dispatch system.

b) Underground extraction:

- Operate low-profile LDH remotely.
- Operate jumbo units (secondary reduction).
- Repair production grizzly.

c) Blasting:

- Manage explosive supply and distribution in magazine, open-pit and underground mines.
- Load blastholes with autonomous equipment, in blasting process, open-pit and underground mines.
- Design blasting sequence, open-pit and underground mines.

The second MQF process considered is **Copper Processing**. Once the ore leaves the extraction stage, it is trucked to Processing to be separated from the rock and turned into high-grade copper. Basically, two main types or mineral exist, sulfides and oxides, which define the type of separation process to be applied. The first process stage, for either material, involves primary crushing through which copper-bearing rocks are reduced in size until the granulometry required for the rock to be taken to the next process step is reached. Later on, the first type is moved to a sulfide and associated byproducts concentration process while oxides are conveyed to a hydrometallurgy process.

The subprocesses involved and their most representative competencies are as follows:

a) Copper oxides processing, hydrometallurgy (LX, SX, EW):
- Stockpile material for leaching.
- Perform cathode stripping.
- Operate electro-winning cells.
- Operate bucket wheel excavator.

b) Copper sulfides processing:
- Operate flotation cells.
- Operate crushing plant equipment.
- Operate SAG mill equipment.
- Operate thickeners.
- Receive and handle reagents.

c) Smelting and electrolytic refining process:
- Bleed molten liquids, flash furnace.
- Operate casting equipment.
- Heat furnaces.
- Operate flash furnace.
- Control smelting-converting in furnaces.

The third and last MQF process is Maintenance. Maintenance represents a core service for equipment, facilities, and systems comprising a mine site. In general, Maintenance is divided into mechanical, testing or predictive; electrical and instrumental Maintenance.

The subprocesses involved and their most representative competencies are as follows:

a) Mechanical Maintenance:
- Maintain lubrication systems.
- Maintain diesel engines.
- Diagnose and replace positive displacement pumps.

b) Electrical-instrumental Maintenance:
- Channel and lay medium-voltage lines.
- Maintain electrical motors and generators.
- Maintain switchboard, power, and control panels.
- Maintain field instrumentation devices.
- Maintain control systems.

TECHNOLOGY AND ITS IMPACT ON THE MINING INDUSTRY

THE FOURTH INDUSTRIAL REVOLUTION

The technological development witnessed throughout the years has made it possible to live with such advances within arm's reach in all areas of everyday life.

The significant changes experienced in our domestic, personal and work activities have prompted us to adapt to new ways, other methods and completely different attitudes to face the world as opposed to how previous generations reacted.

From working with water and steam-powered mechanical equipment the world transitioned to a production line or production chain-based logic and the use of concepts like the division of labor while, at the same time, the use of electric power was first being developed. After that, the world leaped into Information Technology (IT) promoting automated production, until finally the use of cyber-physical systems (CPS), artificial intelligence (AI) the internet of things (IoT) and big data became the cornerstones of development for different industries.

Industrial Revolutions

Many transformations have taken place in the way work is done over time. Factors such as the way in which people communicate and the sources of the energy required to carry out the different tasks have influenced such transformations.

These technological revolution processes, where the industry has played a leading role, have taken the name of industrial revolutions and have turned into key milestones in modern times, reshaping the way we live, work, and think.

During the first industrial revolution, production with mechanical equipment was made possible thanks to the power of water and steam which, by the end of the XVIII and early XIX centuries, allowed for the first time ever, to replace human and animal labor for machines. This period was characterized by the invention of steamboats and steam locomotives, the telegraph, and the manufacture of machines for the metallurgical and textile industries. Considering their nature, these advances were most commonly found in the proximity of port and mine facilities.

Technological progress continued to expand and, after the 1900s, it reached cities which, in turn, gave room to mass production, mainly as a result of the use of oil and electric power. Electric power had a strong impact on the chemical, steelmaking, and automotive industries where the division of labor and production lines were implemented. This second industrial revolution was characterized by inventions such as the diesel engine, the radio, the telegraph, and the telephone.

During the second half of the XX century, and after the first programmable logic controller had been invented in Japan (1969), the arrival of what is known as the third industrial revolution was underway, based on the use of information technology to promote automated production. Under this scenario, nuclear energy, telecommunications, the space and universe, information technology, robotics, and biotechnology are the areas that best represent this period whose success has been achieved with the aid of networks, telecommunications, and massive transportation systems. It should be noted that modern ways of communicating, such as internet, have become organization and management means, with the computer as the crucial tool through which these processes are conducted.

Up to the third industrial revolution, people had been focused on pursuing the means to achieve industrialization development and leverage the opportunities at hand. At the beginning, this enhanced the performance of their raw materials and, later on, the chain was strengthened through the exploitation of natural resources, nearing their depletion, not yet questioning or becoming aware of the need to make a more reasonable or sustainable use over time.

Professor Klaus Schwab, founder of the World Economic Forum, in his book “The fourth industrial revolution” (2016), describes present times as one characterized by the fusion of new technologies with the physical, digital and biological world. The “cyber-physical systems” -such as smart electric power grids, autonomous automobiles, and medical monitoring systems, among others- would be able to interconnect thousands of people at any moment, improving the efficiency of any organization and environmental protection, an issue that prior revolutions had not considered.

INNOVATION PIVOTS	INDUSTRIAL REVOLUTION			
	FIRST (1760 to mid 1800s)	**SECOND** (1870 to 2nd World War)	**THIRD** (1960 to early 2000s)	**FOURTH** (2nd decade of 2000s onwards)
CONTROL	Mechanization	Standardization	Automation	Autonomy
INTEGRATION	Network transportation	Electrification	Reprogrammability	Adaptability
RECONFIGU-RABILITY	Stationary machines	Heavy construction	Reprogramabilidad	Adaptabilidad
SCALE	Factory production	Mass production systems	Digitalization	On demand
SUSTAINABILITY IMPACT	Enhanced performance	Resource exploitation	Resource depletion	Renewability

According to the World Economic Forum estimates, the internet of things is supposed to be playing a fundamental role in this revolution and that the world's economy will receive 14.2 billion dollars in the next 15 years as a result of this process.

As Randstad reported in its article "The fourth industrial revolution is now upon us" (March, 2017), all previous industrial revolutions have disrupted labor. For example, between 1900 and 1970, the United States witnessed how its agricultural and livestock sector dwindled from 41% to 4% (today, it is barely 2%), "as a result of the successive technological and industrial advances and their impact in social conducts".

TIMETABLE OF IMPACT ON INDUSTRIES, BUSINESS MODELS

IMPACT ALREADY FELT	2015 - 2017	2018 - 2020
Increased geopolitical volatility	New supplies of energy and technologies	Advanced robotics and autonomous transport
Mobile internet and cloud technology	Internet of things	Artificial intelligence and automatic learning
Advances in computer power and big data	Advanced manufacturing and 3D printing	Advanced materials, biotechnology, and genomics
Crowdsourcing, sharing economy, and peer-to-peer platforms	Longevity and aging of society	
Increase of middle class in emerging markets	New consumers' concerns on ethical and privacy issues	
Rapid gentrification	Increasing women's aspirations and their economic power	
Changes in work environments and in flexible work contracts		
Climate change, limited natural resources, and transition to a greener economy		

Megatrends in the Fourth Industrial Revolution

In the middle of this turmoil caused by new technologies in the way industries are operated nowadays, some trends have emerged that, after establishing themselves globally, have started to seep into other fields. The first and megatrend is the **internet of things (IoT)**. This refers to the no-turning-back leap into hyperconnectivity; that is, automatic connection between different levels (people / objects). The fact that objects such as telephones, washing-machines, electrical appliances, screens, and other devices are interconnected and are capable of collecting information, like the tastes and preferences of each person, will generate an information system that will require different communication protocols and the need of standardization.

Cyber-physical systems are another megatrend that combines physical infrastructure with software, sensors, nanotechnology, and digital communication technology. Another concept that comes to play a role in this scenario is interoperability, as the capacity of unequal and diverse systems and organizations to interact with consensual and common objectives in order to obtain mutual benefits. In the course of this interaction, the organizations engaged in this process share information and knowledge through their business models, by exchanging data between their respective IT systems. The cyber-physical systems are found at the very basis of this fourth industrial revolution.

Efficient production is the third megatrend playing a part in this process. This concept can also be associated to smart grids because, as it will turn increasingly harder to have access to such basic and widely consumed services as electric power, their production will need to be optimized in order to meet the day-to-day demand. The development of smart electric power grids can be mentioned as an example of the above megatrends. Buildings will be bidirectionally connected to electric power grids, creating a smart grid, where both buildings as well as electric power companies will upgrade their management capabilities with the purpose of maximizing the electric power distribution network to ensure the efficient and sustainable use of this resource.

The smart grids integrate advanced data acquisition technologies, control and communication methods of traditional electric power grids. These involve the combination of electrical infrastructure and information and communication technologies (ICT), generating greater technological convergence and, just as with the first megatrend, an important integration of intelligent electronic devices (IED) of different makes, models, and functionalities.

Collaborative robotics, sensorization, and augmented reality are but other examples of these advances that have become megatrends. As for collaborative robotics, its appearance derives from the latest breakthroughs in robotics technology and miniaturization of electronic components and processors. They are characterized by their lightness, flexibility, and ease of installation. Collaborative robots and sensorization have been especially designed to interact with humans in a shared workspace, free from the need to install safety guards. Their small size, flexibility and affordability set them apart from traditional industrial robots and make them apt, for example, for small and medium-size companies. They offer a quick return on investment, do not require specialized technicians for their mounting and start-up, can be reconfigured to operate at different points of a production line, and enable companies to optimize their productivity. They represent a new era in industrial automation because they allow robots to be installed in industrial areas and processes where, as of today, it had not been possible. This means access to markets that account for 90% of the industry.

In relation to augmented reality, this experience allows the user to view a physical environment residing in the real world through a technological device; that is, the tangible physical elements are combined with virtual elements thus creating an augmented reality in real time. It consists of a number of devices capable of adding virtual information to an already existing physical information. In other words, they add a synthetic virtual portion to actual reality. The role of augmented reality is adding virtual elements to an existing reality rather than creating it from the ground up.

As an example specifically associated to the megatrend efficient production, 3D printing is a bottom-up, additive process intended to construct objects by laying down successive layers of material. The suitable technology will be determined by the materials, esthetics, mechanical properties, and performance required. This technology creates parts by applying additive manufacturing, in contrast to the traditional subtractive process. If placed in parallel with the foundations of the fourth industrial revolution, there is a perfect fit with additive manufacturing.

Number four, and as great megatrend covering the entire spectrum of processes and activities is **big data**. This recently coined expression is used to identify datasets that, due to their huge volumes, cannot be handled with common data management software. Instead of defining big data as huge concrete datasets -for instance, in the order of magnitude of petabytes- the definition would rather describe it as data volumes too large to be managed without the help of new algorithms or technologies. This is why big data is turning into a powerful tool to upgrade the efficiency and quality in organizations while it will gain increasing importance in the coming years.

But, in order to face the new big data-associated scenario, new working tools will be needed. In this sense, Doug Laney (2001) talks about the 3Vs required to correctly interact with big data:

- Volume: The size of available data has been growing at an increasing rate, as opposed to tools and equipment to process such data.
- Variety: big data is not only numbers but also audios, videos, texts which makes it of key importance to possess the knowledge to work and the equipment to process such diverse data types.
- Velocity: data travels at an unprecedented speed. People must work in real time with data that is key, for instance, to prevent fraud or present customized offers to clients.

Digital Transformation: Scope of Work

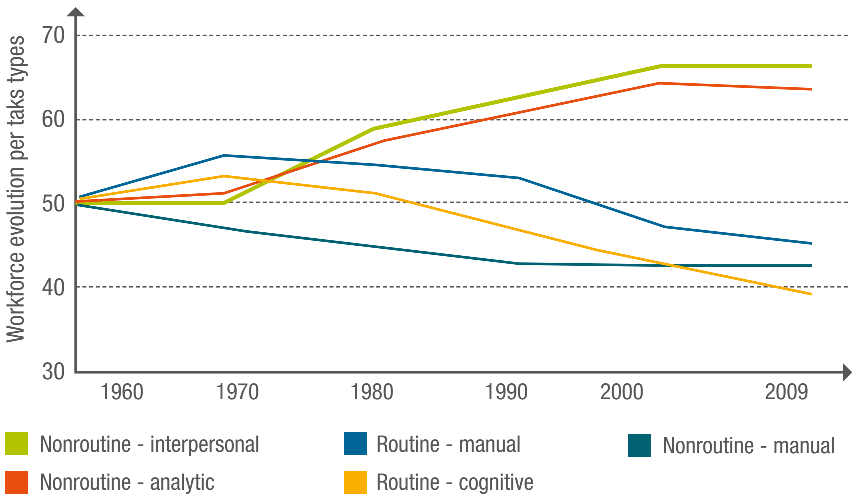
According to the University of Oxford, nearly 47% of the US jobs are at risk of being replaced by computers (Frey & Osborne, 2013). On the other hand, McKinsey Global Institute (2017) concludes that almost half of all work activities have the technical potential to be automated* between 2025 and 2050. This is not far from the vision promoted by Keynes in the 30s when he stated that "the increase of technical efficiency has been taking place faster than we can deal with the problem of labor absorption".

ROUTINE		NONROUTINE		
MANUAL	**COGNITIVE** (Mental)	**MANUAL**	**COGNITIVE-ANALYTIC** (abstract thinking)	**COGNITIVE-INTERPERSONAL**
DEFINITIONS				
Activities such as production and monitoring; work done in production lines.	Activities sufficiently well-defined to be completed by a low qualification-level workers.	Activities that require situational adaptability, visual and language recognition and maybe person-to-person interaction.	Activities that require problem solving, insight and creativity.	Besides the above, these activities require the skill to mutate the actions to be complete based on context, fixing, prioritizing, and reviewing the targeted goals or objective.
AUTOMATABLE?				
Easily automatable and frequently replaced by machines.	Increasingly replaced by algorithms (computer software).	Modest levels of training required (advanced robotics).	Facilitated and complemented by computers but not replaceable by them.	Hardly replaceable: persuasion, negotiation, and people management skills required.
EXAMPLES				
Activities of construction, transport and repair: harvest, classification, repetitive assembly.	**Desk work:** librarian, data entry, records maintenance, or repetitive customer service (Ex.: transactional sales).	**Service jobs assisting others:** drive trucks, clean hotel rooms, prepare food.	**Diagnosis, analysis, and writing:** hypothesis testing in fields of science, engineering, laws, medicine, design, and marketing.	**High situational adaptability:** abstract analytical + management skills (emotional intelligence).

* Automation is understood as the introduction of robots to substitute, total or partially, a function formerly performed by human operators.

Cortés (2016) infers that, while technological advances in themselves are unable to drive changes in the occupational proportions, “automation has caused a sample of workers to leave their routine occupations and sort into “nonroutine” manual jobs (or end up unemployed). In this sense, Autor and Price (Autor and Price, 2013) observe, through a US labor market sample, that the task composition of workers has been mutating and polarizing since 1970. The tendency shows that the growth occurs in the number of positions performing nonroutine (cognitive and interpersonal) tasks, while routine tasks (manual or cognitive) have seen an important decrease.

Workforce 1960-2009 US economy
(all educational tiers)



Adapted from: D.H, & Price, B (2013, June). The changing task composition of the US labor market: An update of Autor, Levy & Murnane (2003). Available at: http://economics.mit.edu/files/9758

Carl Frey and Michael Osborne (Frey and Osborne, 2013) in their study examined how susceptible to digital transformation some positions are, predicting that the service, transport, and jobs associated to logistics and administrative support will be the most impacted. In turn, the World Economic Forum's **Future of Jobs Report** states that, impacted by the disruption of technological change, the following job families will be affected:

Job families impacted
(in thousand jobs)

DECREASING		INCREASING	
Financial operations and businesses	-40	+492	Financial operations and businesses
Office and administrative	-4.759	+416	Administration
Manufacture and production	-1.609	+405	Mathematics and computers
Construction and extraction	-497	+339	Engineering and architecture
Art, design, entertainment, sports and media	-151	+303	Sales and related services
Legal	-109	+66	Education and training

Adapted from: Future of Jobs Report, World Economic Forum.

Then, one may wonder, are digitalization and automation the real problem or is it that companies are not getting prepared rapidly enough? It might seem that, in contrast with previous industrial revolutions, the discussion does not revolve around how workers will be substituted but instead how jobs will be transformed.

If looking into the root cause, one might perceive the need to focus on education in order to ensure that really well trained professionals go out into the job market and face this new work scenario where technology plays the starring role. And this is where STEM Education (Science, Technology, Engineering and Math) comes to play a part. STEM Education gives people the opportunity to develop skills and competencies connected to innovation, regardless of whether or not they will pursue a technical-scientific career. This new learning model is based on the integrated teaching of the above disciplines, instead of independent areas of knowledge, with an interdisciplinary and applied approach. In other words, STEM becomes an essential element in adapting to the arrival of new technologies and whose incorporation implies higher levels of preparation for the new operative model in the face of automation; for example, in the decision-making process.

Competencies for the Smart Industry

"[…] emotion is often the real secret sauce of success in many jobs, high-skill and low" (Colvin, 2016).

Geoff Colvin, author of Humans are Underrated, stated that while it might seem that no job is free from being automated or digitalized, people own traits that are forced to prove. They have learned them through history and determine them in terms of survival; their name is relational skills.

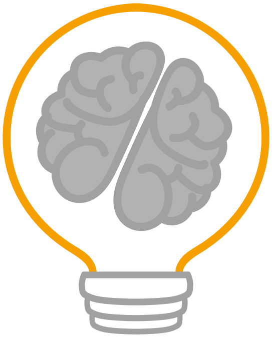
In this sense, Goldin & Katz (1998) point out that the skills required for for non-routine employments and jobs with in-person skills are less susceptible to competition due to their low-cost. Colvin concludes that: "skills of interaction are becoming the key to success". On the other hand, Autor (2015) explains that the increasing importance of social skills in today's labor market would respond to the fact that those tasks and competencies not replaceable by automation are complemented by the latter.

As opposed to Peter Drucker's theory in the 50', Towers Watson and Oxford Economics observed that today's employers would rather have their employees develop competencies such as team or relationship building, co-creativity, brainstorming, cultural sensitivity, and skills to manage diverse employees over those associated to data analysis or project development. In other words, knowledge workers would no longer be apt to successfully interact in a currently relational world, as in the next 5 to 10 years workers that contribute more knowledge will not be required but those capable of adding value through social interaction.

In general, Oosthuizen (2006) adds: "Now, although senior managers are far from obsolete, executives need to become adept in creating innovative new organizational forms needed to manage in an age of machine intelligence"; accentuating creative abilities, leadership skills, and strategic thinking (McAfee, Goldbloom, Brynjolfsson and Howard, 2014).

In other hands, Deming (2017) believes that interaction between people in the workplace is key to maintain team production, as workers with more developed skills could trade tasks at a lower cost and work with other employees in a more efficient manner. This nonroutine interaction and being able to flexibly adapt to changing circumstances, "is at the heart of the human advantage over machines". Or, as Klaus Schwab puts it, "I'm convinced that talent, more than capital, will represent the critical factor of production".

Digital revolution, in itself, will not transform education. We can be prepared for disruption but ¿are people being trained and are their competencies being developed?



10 BEST SKILLS

IN 2015		IN 2020
Complex problem solving	1	Complex problem solving
Coordination with others	2	Critical thinking
People management	3	Creativity
Critical thinking	4	People management
Negotiation	5	Coordination with others
Quality control	6	Emotional intelligence
Service orientation	7	Judgment and decision-making
Judgment and decision-making	8	Service orientation
Active listening	9	Negotiation
Creativity	10	Cognitive flexibility

Adapted from: Future of Jobs Report, World Economic Forum.

Fourth Industrial Revolution in Mining

The so called fourth industrial revolution has raced its way into productive processes and into humanity's everyday life. But, how did it move into mining? Is it already an existing reality in mine sites? Are operations being performed under the mandates of this revolution?

The Table below shows which technologies, in general, will change the way non-renewable natural resources are mined out, considering metallic and non-metallic mining.

TECHNOLOGY	TECHNOLOGY
Drones	Oil, gas, or mineral reserves discovered through hyperspectral images.
Artificial intelligence	Numerical prediction models + AI to assess solar energy resources.
Big Data Digitalization	Use of big data to optimize production and schedule equipment maintenance.
Robotics	Seabed mining.
Biotechnologies Nanotechnologies	Ecoefficient production.
Energy – water - food link	Topography and data collection to determine consumptions.

Now, when the current status of non-renewable resources extraction is examined in detail according to the above-mentioned megatrends derived from the fourth industrial revolution, the following can be said:

First, and in connection with the first megatrend, the **internet of things (IoT)**, the development of autonomous technologies has been a matter of debate for over a decade. Years ago, technologies and operations were unprepared to take the big leap into automation but today, when companies must mine the ore out as rapidly and efficiently as possible to respond to an increasing demand of metals together with the huge technological advances experienced in recent years, the ripe conditions exist to place automation at the service of mining (different autonomous technologies that have penetrated the industry).

Autonomous trucks are a typical example. An autonomous haulage system provides each unit with a high precision GPS device, so that their position is known and controlled from a control room at all times and a wireless network system to ensure the continuous flow of information is maintained.

Additionally, they are equipped with an obstacle detection system that, by means of sensors, is capable of detecting the presence of other trucks, service vehicles, or people working at the mine in which case, the truck will slow down or stop completely.

These system ensure the truck will be operating safely during autonomous loading, haulage, and unloading cycles while still interacting with other trucks, support vehicles, and people moving around the mine site.

In 2008, Codelco Chile's Gabriela Mistral was the first division to integrate autonomous trucks in one of its mining processes.

As to **cyber-physical systems**, robotics is increasingly making its presence felt in mining while its development is exponentially growing. The increasing concern for people's health, integrity and safety together with the fact that its presence in the mining process boosts productivity rates has led the mining industry to set eyes on technology and the solutions it provides.

Cathode stripping is good example of these systems. In past years, this used to be a manual process performed directly by operators; today it is a fully robotized process, equipped with a "cathode stripping machine" in charge of completing with task with robotic arms. The sampling of bulk material is another example –years ago, it was people who took small samples from the surface of the material while today robotic arms obtain more representative samples, as they are capable of penetrating and drawing material from different layers.

While implementing these technologies comes hand in hand with important associated costs, the results would make up not only for the monetary but also the human costs. Thus, people may be deployed from sites likely to present accident risks or from inadequate workplaces due to suspended loads, excessive noise, vibrations, particle exposure, toxic fumes, and entrapment or explosion risks, among others.

Robotics reduces operations costs, optimizing times and improving process effectiveness and safety.

Additive manufacturing is a clear example of efficient production. It seeks to organize and increase the efficiency of production means, considering the freedom of design offered by additive techniques and the absence of limitations that affect other methods. Adaptability stands as another significant advantage as it is able of building totally complex pieces and 100% oriented to each requirement's needs. An example of this is the manufacturing of multimaterial parts; that is, a piece with a single internal layer, featuring certain characteristics and surfaces generated by additive manufacturing of highly wear-resistant materials. There is also the possibility of repairing very expensive parts instead of reworking them; this can be done even *in situ*. Considering the above can be translated into simpler stock management, lower shipping and handling expenses, lower change and repair times this would be highly advantageous for the mining industry.

One of the most daring challenges faced by the mining industry is the incorporation of big data into its everyday tasks and how to employ the output data in a beneficial way for the business. Thus, among the main issues to be decided are the type of data to be collected and analyzed and to be able to collect only the data relevant for the operation under execution while others can be kept in store to be retrieved in the future. The creation of a consolidated dataset is another key challenge for the industry. The complex task of interpreting the collected data calls for the urgent need to put in place different systems, suppliers, platforms, and human capital equipped with the adequate competencies to perform such analysis.

Together with the above, if the internet of things is used correctly, the machines might be equipped with sensors feeding data about their operations into this huge database on a real-time basis.

If big data is used for predictive purposes, mining companies would not only enhance the general reliability of machines but the efficiency of their commercial operations would be improved and they would end up saving millions of dollars. It is known for a fact that with the use of all these autonomous machines, the data generated along the different stages of the mining process will be significantly increased. This data accumulation should have somewhere to be stored and this is where the need to create a big data of mining operations comes in.

Using big data and being able to efficiently manage that information can be translated into competitive advantages for the mining industry, as decisions will be made on the basis of previously unavailable information.

However, none of the proper technologies for data analysis and their subsequent advantageous use to increase productivity are being used today. An example of the beneficial impact big data can have on mining is the possibility of predicting when a piece of equipment is likely to break down or require maintenance. Based on the technology currently in place, IBM is able to predict which part of the equipment is likely to fail through real-time data analysis (mining. com, 2017).

The availability of a mining model based on integrated operations management is a concrete example of how big data can be linked to this chain. This model makes collaborative planning much easier, keeping it focused on critical aspects of the business while being able to face, for example, the high variability of mining processes, reducing losses, efficiently managing energy resources, and keeping people safety issues under control, to name just a few. In other words, it improves efficiency and productivity.

This model is supported by Integrated Operations Centers (IOC), as IOCs is where the reliable information from mining processes is collected and analyzed on-line, thus acquiring a real time view of the operation as a whole. This allows for better informed and integrated decision-making processes.

In this sense, the use of these IOCs could be directly connected to the cyber-physical systems considered to be one of the pillars underpinning the fourth industrial revolution, on the understanding that cyber-physical systems are defined as all devices featuring computing, storage, and communication capabilities in order to control and interact with physical processes. Cyber-physical systems are generally connected between each other and, at the same time, with the virtual world and global digital networks.

The above requires that some competencies be modified or new ones be created based on the knowledge and skills needed to operate automated or autonomous equipment flawlessly.

TECHNOLOGICAL EVOLUTION IN MINING

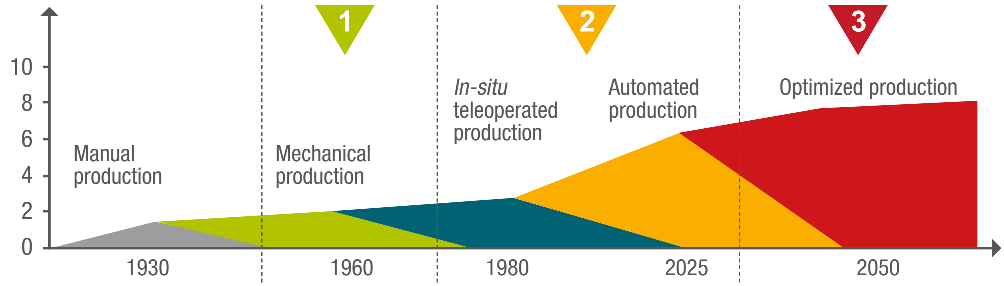
For quite a long time, mining was performed manually, but by mid XX century the first signs of change in its operation were seen and, between 1960-1970, the first pieces of automated equipment were created and incorporated. Transport rails, automated drills, and controlled underground machines (Fisher, S., Schnittger, S., 2012) are but a few examples.

Over time, new machines were created equipped with more modern technologies in order to increase productivity in the mining industry. For instance, and to illustrate how beneficial the incorporation of new technology can be, the existence of larger-capacity trucks has been translated into a significant increase in productivity: payloads went from 25 tons to nearly 400 tons, as of today (plus considerable improvement in energy efficiency this brings along) (Giurco et al. 2010).

Innovating and creating new solutions with current technologies is not an easy task. Despite the above, innovation has been flourishing in mining and new, XX-century technologies have been implemented in the industry. Nowadays many mining companies are going through the same transition in the way they operate their equipment.

In order to respond to the demands and complexities posed by today's markets, Chilean mining companies have been adopting new business models and new ways of operating. However, acquiring autonomous equipment is not enough to step into automated technologies but companies must change their current operations design, be aware of the changes this will bring about in business as well as the impact the incorporation of this new technology will have on workers' competencies. In this sense, the word automation stands as the flagship of this new way of addressing work activities.

Productivity in tons per person/year
(thousand tons)



1 MECHANIZATION

- Process standardization.
- Relevant changes in productive capabilities.
- Equipment operation requires people involvement.

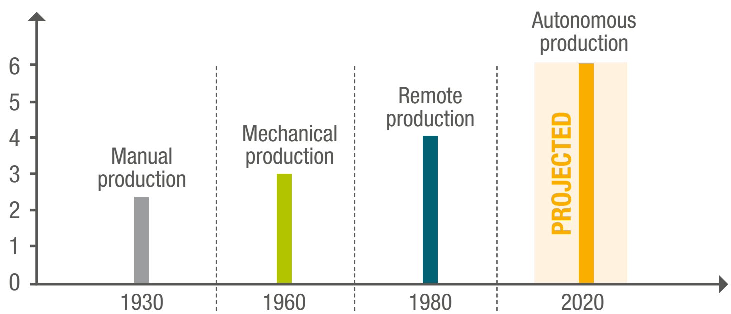
2 TELEOPERATION / AUTOMATION

- Integrated modeling and planning for increased quality.
- Increased visibility of stages in the value chain.
- Detailed information from equipment and plant enabling teleoperated mining.

3 OPTIMIZATION

- Higher level of automation handled by lower number of labor force and teleoperated mining.
- Limited bottlenecks due to adoption of more continuous process.
- High visibility levels along value chain and between operations.
- Interoperability.

Productivity in tons/person



*Source: ABB Integrated Mine Automation

The State of Things: Technological Evolution in Mining Today

In order to have a clear picture of how technology has seeped into mining processes, the first thing to do is to draw some distinctions between the terms automatic and autonomous together with finding out how machines are being operated today, how the system works when run on autonomy mode, and to what extent big data is influencing the way processes are handled.

The Road from Automation to Autonomy

In order to understand how automation operates within our current technological development, a difference must be made between the concepts of automation (automated equipment) and autonomy (algorithms, artificial intelligence) and thus comprehend their evolution in the context of mining technology.

Equipment automation assumes an operator takes all the necessary steps before or after the automated sequence to complete a certain task. Multiple automation sequences are required to allow a piece of equipment to work in a semi-autonomous or autonomous manner. On the other hand, autonomous operation refers to a unit not needing human intervention but completing programmed and previously defined operations.

So, when talking about automation, the term refers to the total or partial substitution of a function that used to be carried out by human operators, either a mental or physical operation (Parasuraman & Riley, 1997). Automated mining equipment operates by means of a programmed routine or is centrally controlled, with relatively few people supervising the operation. In this case, a computerized system is required (Lynas et al, 2011) capable of displaying a real-time performance of the machines so that these can be easily operated, based on the data provided by computers. Different levels of automation can be implemented by incorporating or reducing segmented processes. Thus, in stages such as direct control, the supervision as well as the automated and autonomous systems describe a continuous change of increasing automation levels and less and less human intervention.

Highly autonomous automation can carry out functions only with initiating input from the operator and, at the highest levels, functions cannot be overridden by human operators (Parasuraman, 1997 en Lynas and Horberry, 2011). According to OECD estimates, between 2030 and 2040, 57% of jobs will be automated in OECD-member countries.

Despite their capacity to reduce human involvement, different authors emphasize the permanent importance of human operators. Lynas and Horberry (2011) studied some processes where automation failed because the role of the operator was underestimated; particularly, its capacity to compensate the unexpected or its permanent role in data observation. Sheridan (2002) also states that automated systems often lack the flexibility of people, a key condition to handle unexpected situations. For this reason, there are cases where the total exclusion of operators is not the best of ideas.

In the mining sector, automation has been applied in the last 50 years to enhance efficiency by withdrawing operators from risky environments and by increasing the accuracy and reliability of the data collected and processed and has been employed in environmental management and mineral processing reporting. It has been applied to machinery and to mining process equipment (such as drilling, blasting, loading and haulage), monitoring, control, and communication systems and planning and design tools (Lever and McAree, 2003).

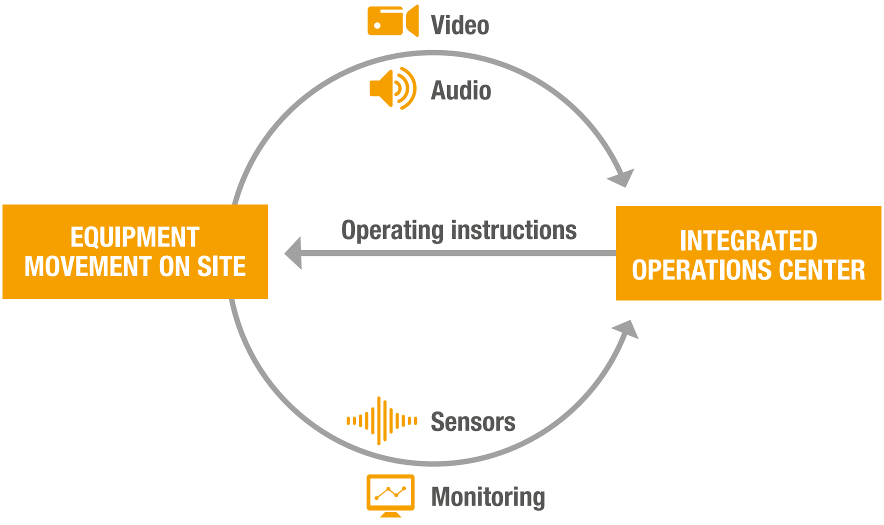
But, how to implement an autonomous operation? The answer contains four key components: Infrastructure changes, new knowledge, better communications, and integrated operations center.

Two options exist to introduce autonomous technology to the mining industry. One of them, the “make it or break it” option, where the change transitions from manually operated to totally autonomous equipment and operators are not needed to run the unit or a more “moderate” option where, on a first stage, a user is required to assist the equipment, then it moves to teleoperation and, finally, it becomes a completely autonomous machine, thus reducing the impact such a disruptive transition might have on workers.

It must be noted that, for this change to occur, changing equipment and machines is not enough but also different processes must be changed to ensure a better performance of equipment. For example, most of the tasks involve the use of surface applications using GPS and, in this scenario, autonomous trucks or equipment would not be enough, if mine facilities are not changed previously. Another change might take place in operators’ knowledge, as their current job would be changed and/or new tasks would be added; this means, qualified human capital would be needed to undertake the new tasks.

Communication is a key factor at the moment of implementing remote operation processes in mining. It must be kept in mind that, when mechanical equipment is used with operators on site, it is these operators who make the decisions based on their vision, background noise, and machine vibrations; that is, they focus all their senses on the task being carried out (Hemani & Hassani, 2009). In contrast with mechanical operation, tele-remote operations should rely on adequate feedback rather than just videos showing how the machine is operating. Mine site facilities should be equipped with good internet connection, an essential element to control and operate machines on a real-time basis (Dadhich, Bodin & Anderson, 2016).

Based on the above -and considering that, when watching how a machine is working on a video there is always the risk of missing or receiving fuzzy images, vibrations, or sounds- there are four devices in charge of providing the corresponding feedback and thus make tele-remote operation possible (Dadhich, Bodin & Anderson, 2016). Direct contact with the machine can occur, as long as intended to improve the conditions of efficiency.



To ensure the success of the above operation, there must be a place especially allocated to monitor the machine performance. For this reason, the integrated operations centers are a key element if teleoperated equipment and/or autonomous equipment is being handled. However, monitoring is not enough but this facility should also serve as a tool where decisions aligned with the interests of the business are made.

Automation in mining has brought along different forms of remote control. This is where machines and processes are supervised and controlled from a site located away from the activity. This includes remote operation (eg, joystick-operated drilling conducted by workers from a distance) and direct teleoperation (eg., controlling the Extraction process from a computer in a control room) (Meech & Parreira, 2011).

These remote control operations have allowed operators to work from safer positions and have led to the centralization of functions that normally present disparate control systems. In this case, people in charge of supervising these systems work in very close proximity. This condition allows users to gain greater awareness of the state of each component involved in the operation, improving the integration of available information, and providing an ample panorama of the entire operation. Nowadays, given the increasing capabilities of communication systems, cutting-edge detection technologies, system processes, and image navigation and technology, remote control centers can be located farther away from mine sites.

Working with integrated operations centers (IOC) calls for the implementation of a certain strategy and changes in processes, technologies, and human capital. This will enable a vision of the entire production chain and the identification of possible problems, maintenance needs, and, in the very site, generate real-time solutions for those problems (Cyliani, s.f).

In brief, it has become increasingly evident that all roads lead to autonomous operation. Among its benefits, the following key points have been identified:

Qualified labor force: due to the incorporation of autonomous technology equipment, a number of functions previously executed by operators will be performed by those units, which raises the question of what will happen with those workers currently developing those functions. Needless to say that the incorporation of autonomous equipment does not seek to replace workers but train and upskill them to carry out new functions and adapt to technological changes occurring at the workplace. Better qualified and more knowledgeable workers is the beneficial legacy from this type of technology to mining companies.

Performance: the performance of autonomous equipment should be more predictable. If operators have less direct control over trucks and other equipment, downtimes should be drastically reduced. This performance upgrade should translate directly into better mine productivity and outputs. If no direct operators are required to handle equipment, productions costs will drop while other operative costs could also be lowered as, once free of human involvement, equipment availability and utilization rates should rise, shift-change downtimes would be reduced as well as unscheduled maintenance (Accenture, 2010). Human involvement would be reduced while efficiency would be increased due to the absence of direct contact with equipment units but only machine-machine connection, which is expected to improve and increase performance (Bloem, van Doorn, Duivestein, Excoffier, Maas, van Ommeren, 2014). Equipment performance could be increased as a result of predictive maintenance instead of scheduled maintenance. New technologies could monitor more accurately the state of equipment in order to identify exactly when maintenance should be conducted.

Safety: the use of autonomous equipment is expected to reduce the occurrence of safety-related events just by significantly eliminating or reducing the presence of operators in machines. Once this presence is lowered, common mistakes are likely to drop or disappear completely. With fewer operators, autonomous equipment can help increase productivity in tougher and more risky sectors (Accenture, 2010).

Sustainable development: nowadays, compliance with formal mining exploitation obligations is not enough for mining companies. They are also required to be connected to local communities, their needs and development with the purpose of mitigating what possible adverse effects their operations may cause, in addition to considering the environmental impact (Moffat & Zhang, 2013). Automated processes can help diminish the environmental impact by modeling the best ways of handling and reducing contamination and probable environmental damage. Prior to introducing automated equipment into the operation, simulations are conducted so that, once completed, organizations can put the equipment to work with no trial and error tests in the field (Dionne, 2014). The incorporation of this type of technology might pave the way for other mining projects or extend the life cycle of those already in progress, having always in mind the impact this type of mine operation may have and what can be done to reduce the negative impact on the community and the environment. The Global Mining Initiative (GMI) raises awareness on the new social-environmental challenges faced by the mining industry today, specifically in relation to sustainable development matters.

Increased productivity: mining productivity is determined by how many ore tons are produced by equipment unit per year. The use of autonomous equipment can have a two-fold productivity increase: equipment use and operator effectiveness.

- Equipment utilization is measured as the number of hours worked in a year without operator-induced downtimes. Autonomy would increase equipment utilization by reducing the downtime hours as, for example, the time lost during shift changes, safety conditions, or other situations that may diminish the time for the operator to work with the machine safely (Accenture, 2010).

- Operator effectiveness is measured by the tons this user moves per hour. Autonomous equipment could nearly eliminate performance variations induced by the operator. For example, if manual operator effectiveness is between 50 and 70%, the use of autonomous equipment could be potentially increased to the range of 90%. This could result in an equipment productivity increase of 20 to 40% (Accenture, 2010).

Equipment Operation Modes

After analyzing the mining processes comprising thus study, three ways to operate equipment can be distinguished: manual, teleoperated, and autonomous.

1. **Manual operation:** the worker sits at the machine and operates it manually. Processes are standardized and relevant changes occur in productive capabilities (ABB Group, 2016).

2. **Teleoperation:** performed with machines controlled by an operator from somewhere else, from a distance. This is done with the aid of cameras, sensors, and software. This mode allows for a better visibility of stages and more detailed data on equipment and its performance is available (ABB Group, 2016). This might well be considered a half-automated process. According to Dadhich, Bodin & Andersson (2016) three types of teleoperation exist:

   a) **In-sight teleoperation:** from an outside position, the operator controls the machine manually, but from a distance.

   b) **Teleremote operation:** from a control room and away from where the machine is working, the operator commands all machine tasks with the help of video and audio fed back from the unit.

3. **Automation:** the machine executes different tasks on its own assisted by the operator who intervenes when human supervision is important.

4. **Fully autonomous operation:** the machine works completely on its own. The operator participates only when high-level commands are needed and to take care of possible emergencies and failures. At this point, the process is completely automated. This type of operation seeks to optimize certain processes, eliminating bottlenecks, and gaining vision of the entire process and operations in progress (ABB Group, 2016).

CURRENT STATE OF THE ART OF TECHNOLOGIES

A data collection survey was undertaken to set a mid-term technological frontier; in the process, a thorough bibliographic search was conducted to have an accurate view of the current reality, in terms of the use of technologies in mining and supplier companies, as key members of the productive process.

The results of this analysis as well as the equipment/machinery used in each process and subprocess and the maximum technological level identified are detailed in the table below:

Extraction: Exploration and Drillings

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
DRILLING MACHINE	The supplier can provide a track-mounted or a truck-mounted version. Truck-mounted units are compatible with international trucks. Also, they are self-regulated to match the type of rock to work with.	TELEOPERATED

Extraction: Open pit

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
DRILLING MACHINE	Up to three pieces of equipment can be handled from a single control station. It is self-regulated to match the type of rock they will be facing.	TELEOPERATED
SHOVELS	Excavators or mechanical shovels are self-propelled machines, mounted on tires or on tracks, with a structure that rotates at least 360° (left and right, uninterruptedly); it excavates the ground, loads, lifts, turns, and unloads material with the bucket mounted on an assembly formed by the boom and arm or rocker arm while the supporting structure or carrier is kept firmly in place. Electric shovels are the largest loader excavators existing in the industry.	MANUAL OPERATION
FRONT LOADER	Equipped with a load-sensitive system and high performance engines, important fuel saving and low gas emissions. Provided with permanent-lubrication rear-axle bearings. Given their great functionality, they can be used in forestry, agriculture, road & highway construction, aggregates treatment, and mining.	MANUAL OPERATION
TRUCKS	The autonomous mine truck's technology is based on the use of GPS satellite signals, together with other ground-based support signals, as the positioning and navigation systems in these haulage machines, without operator or remote teleoperation.	AUTONOMOUS
BULLDOZER	It is a type of caterpillar-tracked tractor used mainly for earthmoving purposes, excavation and pushing with other machines. Though the blade performs a vertical lifting movement, this unit is not designed to load materials onto trucks or hoppers so earthmoving is done by dragging.	MANUAL OPERATION

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
DISPATCH SYSTEM	Dynamic planning system (dispatch system) designed to remotely manage and control the movement of load and haulage equipment with the purpose of meeting daily extraction program requirements. Based on computer technology, it combines the different loading fronts, the type of materials, their destinations, and the equipment associated to the movement of material (shovels and trucks). This is conducted following a daily schedule handled by mine responsible engineers.	TELEOPERATED
EQUIPMENT VITAL SIGNS	Satellite monitoring system for high-tonnage units (mining and production). It allows remote access to equipment operational data to learn the condition of major components. Designed to help reduce maintenance costs and keep maximum availability and reliability.	MANUAL OPERATION
GYRATORY CRUSHER	The automation system simplifies the operation and provides real-time information on the crusher status.	AUTONOMOUS
JAW CRUSHER	High automation level and excellent interlocking features, one or more units can be controlled by a single operator.	SEMIAUTONOMOUS
CONE CRUSHER	The automation system simplifies the operation and provides real-time information on the crusher status.	AUTONOMOUS

Extraction: Underground

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
LHD	Operation from a special control room versus on-board operation.	TELEOPERATED
PRODUCTION JUMBO	The automated control of different unit functions substitutes human experience and the numerous commands from toggles and switches by computerized data based on sensors and software. The most beneficial advantage of automation is that the control system will not go astray from what it was taught to do.	TELEOPERATED
ROCK BREAKER	With the optional control system, it can add automated easy-to-use functions to increase safety, accuracy, and production.	TELEOPERATED
DUMPER	Self-propelled, very resistant vehicle on large wheels and an open box. Used to transport large volumes of earth or rock.	MANUAL OPERATION
LOCOMOTIVE	Characterized by its highly efficient sliding and antisliding protection system and its pioneering AC traction technology that also guarantees reduced maintenance and downtime costs. It can be divided into four separate modules to expedite transport and underground assembly.	SEMIAUTONOMOUS

Processing: Concentrate process

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
ROD MILL	Automatic, energy-saving operation.	AUTOMATED
BALL MILL	It analyzes a wide range of signals and triggers automatic adjustments in order to manage the equipment and process performance which is translated into a better mill performance.	AUTOMATED
SAG MILL	It analyzes a wide range of signals and triggers automatic adjustments in order to manage the equipment and process performance which is translated into a better mill performance.	AUTOMATED
SCREEN	Vibrating screens consist of mechanical and electrical, low-amplitude, high-frequency components covered by a perforated sheet or mesh with specific size openings as a surface. These meshes or sheets are mounted on a frame anchored to the equipment walls known as vibrating box. This slightly inclined box is moved by a motor that sets in motion a pulley and a shaft installed across the structure. It also has a feed box and a base frame supporting the whole structure with the dampers.	MANUAL OPERATION
PEBBLES CRUSHING	The automation system simplifies the operation and provides real-time information on the crusher status.	AUTOMATED
HPGR	The speed and pressure can be readjusted to change ore conditions and meet downstream circuit requirements.	SEMIAUTONOMOUS
VERTICAL MILL	The automation system simplifies the operation and provides real-time information on the mill status.	AUTOMATED
HYDROCYCLONES	The system analyzes a wide range of signals and triggers automatics adjustments in order to manage equipment and process performance which is translated into a better mill performance.	AUTOMATED

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
COLUMN CELLS	The application of advanced process control for flotation circuits has been designed to manage the flow of material through the flotation circuit and slurry and froth levels.	AUTOMATED
CELDAS DE FLOTACIÓN	The system monitors a number of signals in the plant's control system and manages a series of key actuators to achieve maximum recovery and concentrate grade.	AUTOMATED
ESPESADOR	Simple and easy-to-use controls that keep the process running in an efficient way. In order to ensure that everyone, from operators to technicians, can easily navigate and use the system, the platform uses a common and intuitive graphical user interface with clear and accurate representations of the production process.	AUTOMATED

Processing: Hydrometallurgy

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
BELTS	Equipped with process control and automation.	AUTOMATED
STACK	Once prepared, the ore is placed in stacks of trapezoidal cross-section with a height determined by calculation (heaps) which is later on irrigated with a prepared solution. Once the solution has percolated all through the heap, the pregnant solutions are collected and taken to the process plant to recover the mineral component (salt or metal).	MONITORING, VISUALIZATION
RADIAL STACKER	A single operator can control all system functions, supervise the machine status, and do the problem solving either from a remote control room or from an operator's ergonomically optimized cabin.	AUTOMATED
BUCKET WHEEL EXCAVATOR	A continuous production machine within which the functions of starting, loading and transport are separated; the first two are carried out by the bucket wheel and the last by a system of conveyor belts.	MANUAL OPERATION
ELECTROLYTIC CELLS (EW)	It is used to break down, by means of electric current, ionized substances called electrolytes. Electrolytes can be divided into acids, bases or salts. The dissociation or separation process that takes place in the electrolysis cell is called electrolysis.	VISUALIZATION
CATHODE WASHING MACHINE	It automatically performs all the material-handling tasks for anode scrap. The scrap washing machine will efficiently wash and pack scrap anodes in copper electrorefining plants for recycling. It uses closed recirculating wash water for a clean, dry, and slime-free wash process.	AUTOMATED

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
CATHODE STRIPPING MACHINE	The infeed conveyor receives the load of cathodes and takes it to the stripping station. Once the conveyor gets to its final position, a robotic manipulator picks the cathode, drives it through the washing station and inserts the cathode into the stripping station where the unit is flexed, hammered, and stripped to detach the copper from the blank. The sheets of copper are deposited on a cathode conveyor which is advanced step by step until it reaches the corrugating station. At the end of the cathode conveyor, a manipulator takes the sheets and packs them together on the package conveyor. The blanks earlier detached in the stripping station are picked by another robotic manipulator and placed over an outfeed conveyor through which the cathode is returned to the cell.	AUTOMATED

Processing: Pyrometallurgy

EQUIPMENT	OPERATION	MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED
SMELTING FURNACE (SF)	The smelting furnace technology consists of a continuous concentrate smelting and converting process, developed by Outkumpu, which uses the heat generated from the reactions of the oxygen contained in the air of the process with the iron sulfides contained in the concentrate fed to the reactor. Depending mainly on the concentrate mineralogical or chemical characteristics, the flows and blown oxygen-enriched air, important amounts of heat will be generated in the reactor, enough for a totally autogenous process, where cold recirculating material are also smelted with copper or cold load generated in the productive process and used to regulate the furnace's temperature.	AUTOMATED
ELECTRIC SLAG CLEANING FURNACE	The ESCF is where Fe3044 contents are reduced, the physical-chemical properties of the slag are improved and copper particles separation and sedimentation is optimized. The resulting white metal contains 70% copper and the disposable slag keeps a nearly 0.70% of copper content.	AUTOMATED
FLASH FURNACE	The reaction tower is equipped with a burner where the load is fed. A main lance, with enriched air, facilitates its supply with the ensuing reaction of sulfide contents. This generates the smelting heat required for proper process performance. Here the material is instantly smelted (flash) producing blister copper, slag, and metallurgical gases with high S02-contents (35%- 45%).	AUTOMATED

IMPACT ON MINING PROCESSES AND COMPETENCIES

DEFINITION OF INSTRUMENTS AND ANALYSIS VARIABLES

Based on the conceptual framework and the information reviewed for this study, two analysis scenarios were defined: one directly connected to the fourth industrial revolution, defined as the **digital transformation** era; and, a second one, called **technological evolution**, on the understanding this implies a 5-year look into the future in the mining industry in Chile.

With regard to **digital transformation**, functions were categorized and classified into routine, nonroutine, manual, and cognitive functions. As for **technological evolution**, functions were classified as follows: if the job is done manually, if teleoperated, automated, or if it is done autonomously.

DIGITAL TRANSFORMATION

How digitalized are the above competencies today? What are their digitalization projections? In order to respond these question, four activity types were defined within the competencies:

a) **Routine:** activities performed on a repetitive basis or very frequently, according to d etailed procedures (easily automatable). In turn, these activities are subdivided into:

a.1) Ruotine Manual: activities like production and monitoring; tasks carried out in production lines. Easily automatable and frequently replaced by machines.

a.2) Ruotine Cognitive-mental: activities sufficiently well-defined to be completed by low-qualification workers in developing countries with minimum discretion. They can be easily replaced by algorithms (computational software).

b) **Nonroutine:** activities whose completion requires work pace changes; for example, specialized production tasks. Three types can be found:

b.1) Nonruotine Manual: activities requiring situational adaptability, visual and language recognition and, maybe, person-to-person interaction. They require modest levels of training. They can be substituted by advanced robotics.

b.2) Nonruotine Cognitive-Analytic: activities requiring problem solving, insight, and creativity. They are facilitated and complemented by computers, but not replaced by them.

b.3) Nonroutine Cognitive-Interpersonal: besides the above, these activities require the skill to mutate the tasks being carried out based on context, fixing priorities and reviewing. Persuasion, negotiation, and people management skills are also required.

c) Manual: activities like production and monitoring, tasks completed in production lines.

d) Cognitivo: activities that call for problem solving, insight, persuasion, and creativity.

TECHNOLOGICAL EVOLUTION

What new technologies have successfully penetrated and stayed as part of the competencies examined in this analysis? How have work competencies adapted to them? Four levels have been established in technological evolution:

a) Manual Operation: the worker sits at the machine and operates it manually.

b) Teleoperation: machines controlled by operator, from a distance with the aid of cameras, sensors, and other software.

c) Automated Operation: machines execute a number of tasks on their own, assisted by an operator who participates in the job when human supervision is required.

d) Autonomous Operation: machines execute all tasks on their own. The operator is involved only when high-level commands are needed.

As for measurement instruments and with the purpose of delving further into the reality of the mining industry in Chile – both in technological-related trends as well as in human resources– a series of interviews were made with process-responsible parties in mine sites (operators), mining suppliers (suppliers), and executives engaged in innovation activities (innovation) of mining firms.

This set of interviews was aimed at getting acquainted with the labor scenario being faced today, considering the impact caused by the disruption of new technologies. To that end, the interviews were organized in four sections: learn about the process vision; the associated technology; types of operations in the face of the new technologies (competencies); and a 5-year change perception.

The interviews were organized as follows:

SECTION	OPERATORS	SUPPLIERS	INNOVATION EXECUTIVES
Part I: Process description	General overview of processes and their main critical equipment.	Identificar en qué proceso está presente su oferta y equipos/ sistemas asociados.	Visión de las compañías mineras con respecto a la incorporación de tecnología a los procesos.
Part II: Technologies associated to process/equipment and technological continuum.	Identify equipment's technology and its technological level. Detect technological level changes in the last 5 years.	Tecnología asociada a su oferta de equipos/ sistemas. Identificación de barreras de entrada a implementación de tecnologías.	Nivel de desarrollo tecnológico de los procesos en las compañías mineras. Identificar cambios tecnológicos y la adaptación al cambio.
Part III: Competencies of workers associated to technology.	Identify level of development of competencies associated to technology and workers' technological command. Competency upgrades and/or adjustments.		
Part IV: 5-year technological change perception.	Vision of technological changes within 5 years.		

Interviews with People in charge of Technology in Mining Companies

A total of 26 interviews were made: 10 with mining firms, 12 with supplier companies, and 4 with innovation experts. Participant organizations were as follows:

Mining companies	Suppliers	Innovation executives
• Anglo American, Chagres • AMSA, Centinela • AMSA, Pelambres • AMSA, Antucoya • CODELCO, DMH • BHP, Escondida • CODELCO, Andina	• Komatsu • Aplik • Modular • Jigsaw - Hexagon Mining • Atlas Copco • Yokogawa • Orica • AMTC • Phoenix • Finning • Sandvik • FLSmidth	• FCH • CODELCO, Chuquicamata • AMSA • CODELCO

The interviews revealed the participants hold different views regarding the adoption of new technologies.

In mining organizations, technological levels are much dependent on the business strategy and on how involved the executives are in incorporating the technologies into processes. On the other hand, suppliers place high-technology solutions in the market, but are faced with the challenge of facilitating their adoption by mining firms.

As of today, not all the pioneering technologies available in the market have been adopted by mining companies but they have been gradually incorporating technological changes and/or solutions. For example, in open-pit mines, only one operation is working with autonomous trucks while, at the plant, the idea of process automation is assumed as an impending change and automation is already present in most of its mine tasks.

On the other hand, today suppliers can offer monitoring systems, especially for extraction subprocesses, which can help reduce risk exposure by workers. At present, these same suppliers are moving to big data and artificial intelligence, as equipment teleoperation and process automation technologies are already available.

In the opinion of suppliers and mining firms, the main difficulty in adopting new technologies lies in people adaptation and the availability of expertise to complete the implementation. Resistance to change and gaps in people's training are observed.

According to the above, technological change processes must go hand in hand with change management. Two groups of workers can be identified: one groups under 25 years old who are very skilled in technology and absorb it rapidly but lack the necessary experience to made decisions in business processes; and a second group formed by people over 50 years old that, despite having the necessary knowledge and experience in processes, have difficulty in digesting technology easily. Effective change management should address this issue.

Validation workshops for macroprocesses

MQF Competency Classification workshops were organized as part of the data collection process, in accordance with the above-mentioned analysis variables.

The workshop covered:

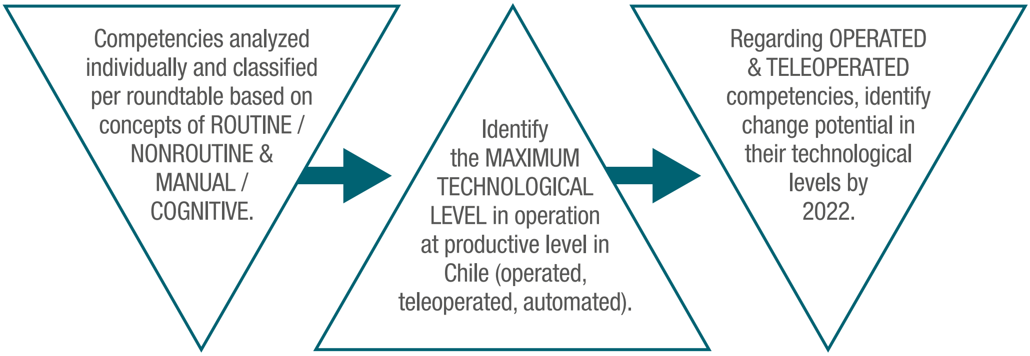
1. Workshop context:

a. Presentation of study objectives and its stages.
b. Presentation of Mining Qualifications Framework (MQF).
c. Presentation of conceptual framework for the study.

2. Activities of competency analysis per process:

a. Competency classification per process.
b. Current categorization of technological level of competencies per process.
c. Analysis and projection of competencies to 2022.

With respect to the development of activities, the methodology to be applied in the analysis of competencies was designed as follows:



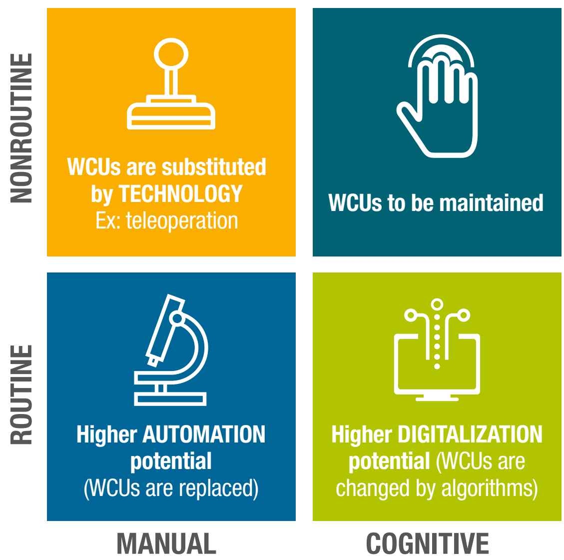
DIGITAL TRANSFORMATION

Based on the theoretical framework and analysis variables defined in this study -where tasks were classified as routine/nonroutine and manual/cognitive and their maximum change potential was defined- and expert judgment gained from interviews and technical work roundtables where the current and 5-year status of productive functions is described based on the use of technologies, below is a description of the results drawn from the analysis run for each process and subprocess.

It must be noted that the hypothesis proposed on the basis of the conceptual framework are but a reflection of what has been going on through the years, regarding the type of tasks/jobs and their evolution through time. Thus, and to ensure this study is better understood, below is description of the segments defined and the results derived from each classification, in terms of their hypothesis.

Definitions

On a first stage, two axes are defined: a horizontal axis to indicate whether a task is manual or cognitive and a vertical axis to specify if it is a routine or nonroutine task. When these variables (axes) intersect, four quadrants and their respective hypothesis are generated in relation to their maximum change potential.



The hypothesis associated to the first routine/manual quadrant states that its maximum change potential resides in automation.

Higher automation potential: activities found in this quadrant belong to competencies associated to the production and monitoring of processes as above described and defined that require physical effort. For example, line production activities are done the same way and repeated over and over. This translates into their easy and frequent substitution by machines.

The second hypothesis, associated to the routine/cognitive job quadrant, shows that their maximum change potential points to digitalization.

Higher digitalization potential: the competency description in this quadrant is related to the identification of variables that have an impact on a result whose algorithm can be identified and replicated. These are clearly-defined and repetitive activities but whose determination has required cognitive efforts and, for this reason, are usually translated into computer software.

The third hypothesis, connected to the nonroutine/manual task quadrant, defines teleoperation as its maximum change potential.

WCUs substituted by technology (eg. teleoperation): this quadrant contains competencies requiring situational adaptation skills associated to processes and activities pertaining to a workflow where constant and distant decision-making is required and that, in the future, might give way to the incorporation of advanced robotics.

Finally, a fourth hypothesis, associated to the nonroutine/cognitive quadrant, describes functions that will not be subject to future changes.

WCUs to be maintained: this quadrant contains all those competencies requiring skills such as problem solving, insight, and coordination, all of them based on the development of analytical thinking and that, despite the fact they might well be computer-assisted, could not be substituted. Besides the above described, there are also those skills connected to scenario-based decision-making, while maintaining full awareness of a situation, setting priorities, and devising a plan to accomplish the desired objectives and goals. Persuasion, negotiation, and work team management skills are found in this segment and, just as the above, are very unlikely to be replaced.

Based on the above hypothesis, a review was conducted and competencies were assigned to each quadrant defined, in order to have an initial proposal available for the review and validation by process and subprocess experts participating in the technical roundtables which, finally, defined the results below.

Potential Impact of Technological Transformation in Mining

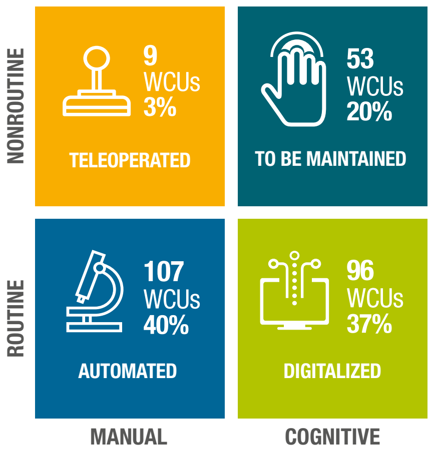
In all, 265 competencies were analyzed and classified corresponding to Extraction (72), Cu Processing (116), and Maintenance (77) processes, as described in the 2017 MQF version in order to define their maximum change potential on the basis of the above hypothesis. The work methodology was based on expert-judgment validation taking as a basis an initial proposal, regarding maximum change potential.

According to the distribution, most competencies are seen to present a maximum change potential in the future (digital transformation) that will tend to:

- First, to automation, as jobs done repetitively and according to procedures described in great detail have historically been replaced by this type of technology.
- Second, to digitalization, on the understanding these will be the functions enriched and complemented by algorithms that make tasks easier and provide more information to be acted on in decision-making processes.
- To a very lesser extent as compared to others, to teleoperation. This could be accounted for by the fact that technology is already present in most equipment and processes.

On the other hand, and as in opposition to competencies that will present a maximum change potential, a lower number will be maintained in the way they are performed today, being more associated, as they are, to coordination and supervision functions.

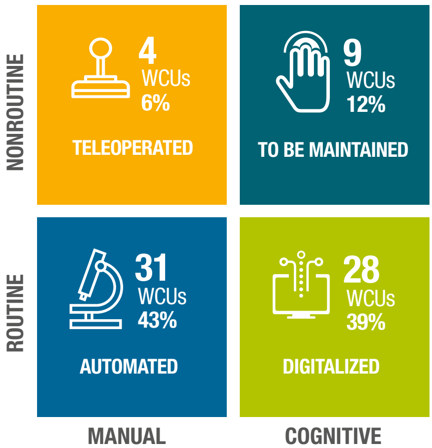
In short, mining will be impacted by digital transformation and multiple change opportunities will open for this industry in the future as, in general, the Extraction, Cu Processing, and Maintenance processes might incorporate the use of emerging technologies. The challenge will be for mining companies to be able to implement these new solutions and reskill the human capital responsible for such technologies.



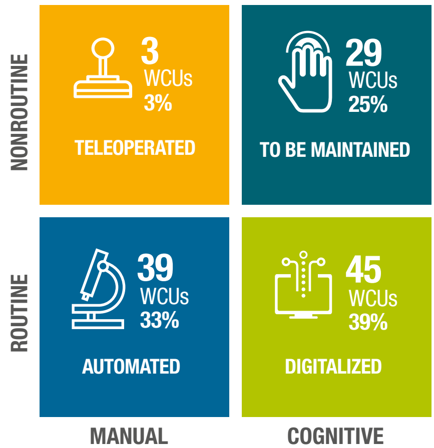
Potential Impact of Digital Transformation per Process: Extraction, Cu Processing, and Maintenance

In a second level of analysis, where the competencies based on the variables defined for each process under review were classified, the results were as follows:

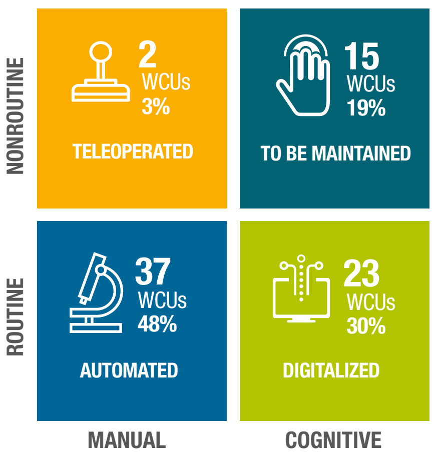
EXTRACTION
Total: 72 competencies



PROCESSING
Total: 116 competencies



MAINTENANCE
Total: 77 competencies



As for **Extraction**, automation is ranked first as the maximum change potential while digitalization is in second place, which could be accounted for by current trend in mining toward safety aspects, favoring operation from a distance.

Additionally, and while a lower number of competencies involved in this process will move to teleoperation, considering that most equipment and functions already have this condition, this number will be even larger than those found in Maintenance and Processing, since most Extraction equipment, being mobile, are more feasible to incorporate that technology.

Finally, Extraction contains the lowest number of competencies likely to be maintained (supervision and coordination) when compared to other processes. This could be explained by increasingly advanced dispatch systems that cause these type of functions to be in retreat.

As for **Cu Processing**, most of its competencies' maximum change potential will tend to digital transformation, which is consistent with many of its functions being already automated; thus, the greatest future challenge lies in leveraging these functions by putting in place software and algorithms that impact and strengthen the decision-making process.

Also, and in relation to other processes, Cu Processing is the one with the highest number of competencies to be maintained, as it includes integrated and continuous subprocesses requiring more variables to be controlled which, in turn, calls for supervision and control competencies.

In the case of **Maintenance**-related competencies and their distribution in the above quadrants, the maximum change potential will tend to automation as this process, in opposition to Processing and Extraction, presents a lower level of technological development.

Potential Impact of Digital Transformation: Extraction Process and its Subprocesses

In a third level of analysis per subprocess, Extraction provides the following results:

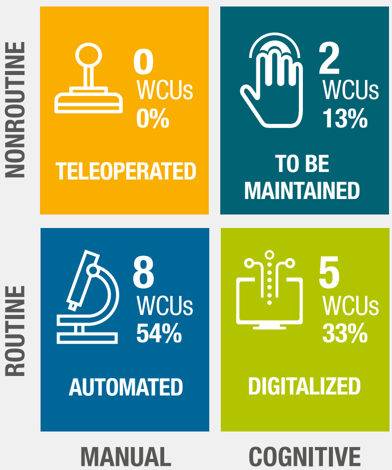
Open Pit Subprocess

Its maximum change potential would lean to Automation. This considering the challenge for some time now existing in mining to remotely operate the mobile units being used at the mine; for example, the operation of high-tonnage trucks.

The autonomous equipment tendency is not only inclined to high-tonnage trucks but also to machines like excavators which should also start to be automatically interconnected (internet of things).

Digitalization comes up as the second change potential, in terms of complementing with algorithms the performance efficiency of ancillary equipment.

Total: 15 competencies



Example of competencies

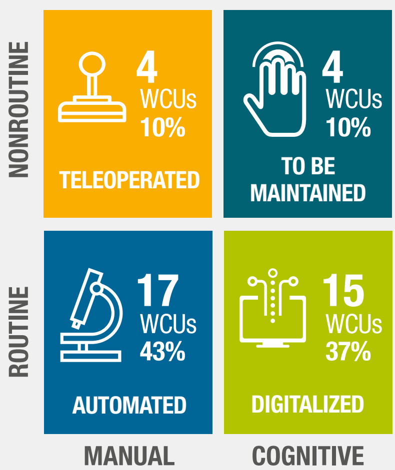
• No competencies assigned to this quadrant.	• Coordinate mining dispatch system. • Supervise extraction process.
• Operate high-tonnage truck. • Prepare and make ready area with crawler-mounted tractor. • Conduct drillings in open pit.	• Operate production excavator. • Load material with front loader mobile equipment. • Load material with shovels.

Underground Extraction Subprocess

In this case, all change-impacted competencies tend to teleoperation due to their connection with repair and installation activities susceptible to being done from a distance, basically, for people safety reasons.

It is also observed that more complex pieces of equipment will be susceptible to being digitalized -eg, jumbos and less complex units will move to automation, like the mobile rock breaker. Additionally, and consistent with this type of activity, coordination and supervision are the competencies to be maintained.

Total: 40 competencies



Example of competencies

- Repair production drift.
- Repair grid grizzly.
- Install vent, drainage, compressed-air, and water system services in underground mine.

- Coordinate mine preparation process.
- Supervise extraction process.
- Monitor extraction process.

- Operate LHD remotely.
- Operate mobile rock breaker.
- Operate ore conveyor belts.

- Operate reinforcement equipment (shotcrete).
- Prepare development blasting.
- Control ventilation inside mine.

Blasting Subprocess

Its greatest change potential is inclined to digitalization which might be explained by the fact that most of its functions, particularly those related to programming, design, and administration, will be complemented with algorithms and systems conducive to better decision-making processes; for example, modeling and design of blasting sequences.

Just as in the previous process, it is observed that competencies associated to more complex equipment will be susceptible to being digitalized -eg, explosives trucks and less complex units will move to automation, like the mini front loader. Finally, coordination and supervision are the competencies to be maintained.

Total: 17 competencies

	MANUAL	COGNITIVE
NONROUTINE	0 WCUs 0% TELEOPERATED	3 WCUs 18% TO BE MAINTAINED
ROUTINE	6 WCUs 35% AUTOMATED	8 WCUs 47% DIGITALIZED

Example of competencies

Teleoperated:

- No competencies assigned to this quadrant.

To be maintained:

- Ensure blasthole conditions in blasting process, open-pit and underground mines.
- Supervise blasting process in open-pit mine.
- Supervise blasting process in underground mine.

Automated:

- Load blasthole with autonomous equipment in blasting process, open-pit and underground mines.
- Operate mini front loader in blasting process.
- Prepare conditions to load blasthole with factory truck in blasting process, open-pit mine.

Digitalized:

- Manage supply and distribution of explosives in magazine, open-pit and underground mines.
- Design blasting sequence in open-pit and underground mines.
- Load blastholes manually in blasting process, open-pit and underground mines.
- Schedule blasting sequence in open-pit and underground mines.

Potential Impact of Digital Transformation: Cu Processing and its Subprocesses

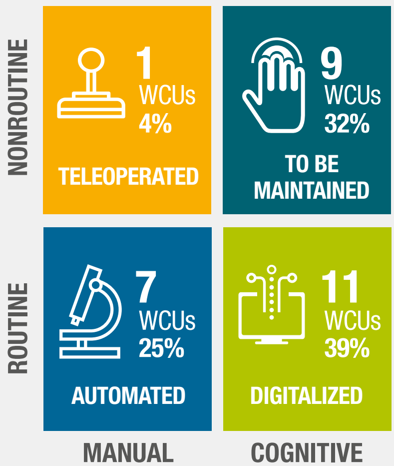
The following is observed in the Cu process and its subprocesses:

Concentrate Subprocess

This subprocess presents the lowest number of competencies likely to be automated, as most of the functions are already conducted from a distance and have integrated the technology fit for the purpose.

On the other hand, the maximum change potential will tend to Digitalization while the affected competencies will be those intended to control secondary processes, such as packing, loading, and dispatch of molybdenum and tailings transport in the concentrate.

Total: 28 competencies



Example of competencies

Teleoperated:
- Add grinding media.

To be maintained:
- Control Mo concentrate filtering process.
- Control SAG grinding process.
- Supervise concentrate processing.

Automated:
- Operate (on site) Mo concentrate packing, loading, and dispatch processes.
- Operate equipment for long-distance slurry transport.
- Operate thickeners.

Digitalized:
- Operate regrinding and grading equipment.
- Operate crushing plant equipment.
- Operate and control moisture filtering processes.

Hydrometallurgy Subprocess

As opposed to the concentrator, this subprocess should congregate the largest number of competencies tending to automation, as an important portion of them are still performed on site, such as stockpiling and cell operations.

This subprocess also presents the largest number of competencies most likely to be teleoperated, with respect to concentrate, smelting, and refining, considering the discontinuous operation of equipment, like the bucket wheel excavator and the stacker that might become part of the teleoperated equipment as their next step toward technological evolution.

Just like in the previous subprocess, competencies dealing with the control of secondary process are the ones moving toward digitalization while those linked to the control of strategic processes, like crushing, SX, and EW, are to be maintained.

Total: 24 competencies

	MANUAL	COGNITIVE
NONROUTINE	2 WCUs 8% TELEOPERATED	7 WCUs 29% TO BE MAINTAINED
ROUTINE	11 WCUs 46% AUTOMATED	4 WCUs 17% DIGITALIZED

Example of competencies

	MANUAL	COGNITIVE
NONROUTINE	• Stockpile material for leaching. • Change anodes and cathodes.	• Control EW processes from control room. • Monitor electrolyte conditions. • Supervise leaching and solvent-extraction processes.
ROUTINE	• Strip cathodes. • Operate electrowinning cells. • Operate bucket wheel excavator.	• Control cathode dispatch. • Control ore sintering plant. • Control leaching process. • Coordinate electrode renovation.

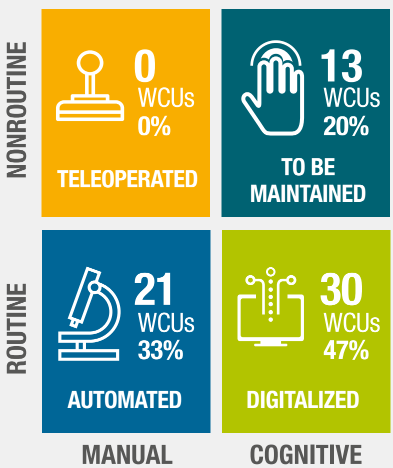
Smelting/Refining Subprocess

In smelting and refining, the greatest change potential will lean toward the digitalization of high-complexity functions, given the implementation of control rooms. This means that programs, models, and designs will have to be generated for future operation.

The maximum automation potential will be concentrated on ancillary or secondary equipment; for example, forklifts, front loaders, bridge cranes, among others.

Though automation should be its maximum potential, some functions and machines could be teleoperated for safety reasons; for example, some ancillary pieces of equipment.

Total: 28 competencies



Example of competencies

• No competencies assigned to this quadrant.	• Supervise compressed-air production. • Maintain smelting furnace refractories. • Supervise sulfuric acid production.
• Bleed molten liquids, flash furnace. • Operate lug-cutting machine. • Operate starting cathode preparation machine.	• Transport smelted, heavy material with bridge crane. • Handle smelting tilting furnace. • Monitor electrolyte conditions.

Potential Impact of Digital Transformation: Maintenance and its Subprocesses

The following can be mentioned about Maintenance and its mechanical, electrical, and instrumental subprocesses.

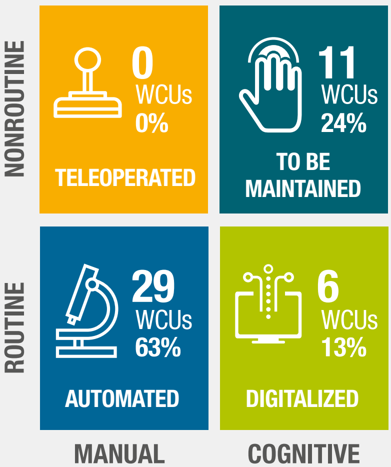
Mechanical Maintenance Subprocess

In Maintenance and its subprocesses, the competencies most susceptible to being automated will be those associated to mechanical Maintenance, given the increasing need to generate a CONMON (Condition Monitoring) process that includes this technology.

Considering the above and that most of the competencies in this subprocess are susceptible to being automated, the greatest challenge will be posed by the insertion of robotics in mining operations; for instance, to achieve the maximum change potential.

On the other hand, this subprocess will maintain the competencies associated to the coordination and diagnosis of stationary and mobile equipment.

Total: 46 competencies



Example of competencies

Teleoperated:
- No competencies assigned to this quadrant.

To be maintained:
- Coordinate and supervise conveyor belt vulcanization/replacement activities.
- Maintain hydraulic systems (specialists).
- Change parameters of mining equipment motors with electronic tools.

Automated:
- Maintain mechanical brakes.
- Maintain lubrication systems.
- Maintain pneumatic systems.

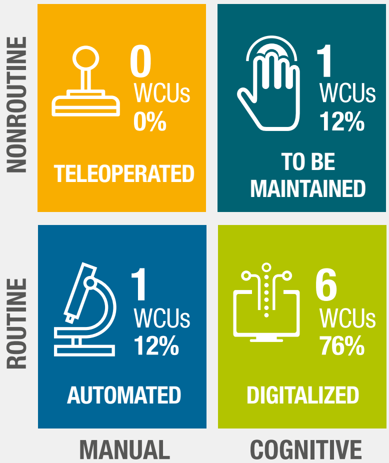
Digitalized:
- Maintain temprature regulation systems.
- Operate bridge crane (mechanical Maintenance).
- Perform analysis and interpret NDT tests.

Instrumental Subprocess

The maximum change potential for its associated competencies tends toward digitalization which might be explained by the processing and analysis of data this subprocess will be requiring in the future.

The integration of programs, for example, to provide maintenance to certain control equipment and systems, will pose a real challenge in terms of availability of the necessary artificial intelligence.

Total: 8 competencies



Example of competencies

• No competencies assigned to this quadrant.	• Maintain ionizing equipment.
• Maintain variable frequency drives.	• Maintain data transmission network systems. • Diagnose pnumatic control systems.

Electrical Subprocess

In the electrical subprocess, the competencies most likely to become digitalized are those associated to equipment diagnosis whose tendency will move to the integration of algorithms in the decision-making process.

Conversely, those to be maintained have to do with medium-voltage lines; mainly, due to environmental and logistic conditions.

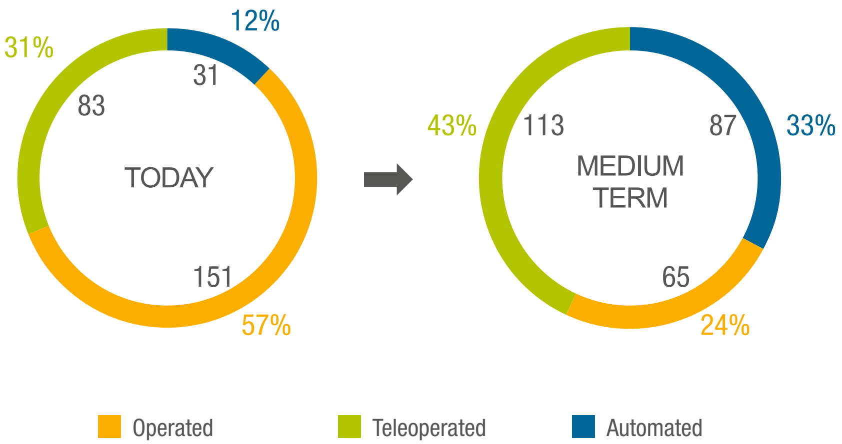
Total: 23 competencies | **Example of competencies**

	MANUAL	COGNITIVE	Example of competencies (manual)	Example of competencies (cognitive)
NONROUTINE	2 WCUs 9% TELEOPERATED	3 WCUs 13% TO BE MAINTAINED	• Maintain electric generators and motors. • Maintain mining equipment motors and generators (specialist).	• Channel and lay medium-voltage lines. • Channel and lay medium-voltage lines (specialist). • Maintain energy meters (specialist).
ROUTINE	7 WCUs 30% AUTOMATED	6 WCUs 48% DIGITALIZED	• Maintain switches and disconnectors. • Maintain low, medium, and high voltage systems. • Maintain switchboard, power, and control panels.	• Maintain low, medium, and high voltage systems (specialist). • Monitor mining equipment performance with electronic tools. • Change parameters of mining equipment motors with electronic tools.

TECHNOLOGICAL LEVEL

In the course of technical roundtables1, and based on expert judgment, representatives from different mining and supplier companies determined the technological level for the 265 competencies analyzed; that is, if these are either operated, teleoperated, or automated. Additionally, a 5-year time horizon was projected to evaluate how they will behave. In other words, whether these competencies remain intact or are modified, in line with the changes experienced by the technological level.

The analysis reported the following results:



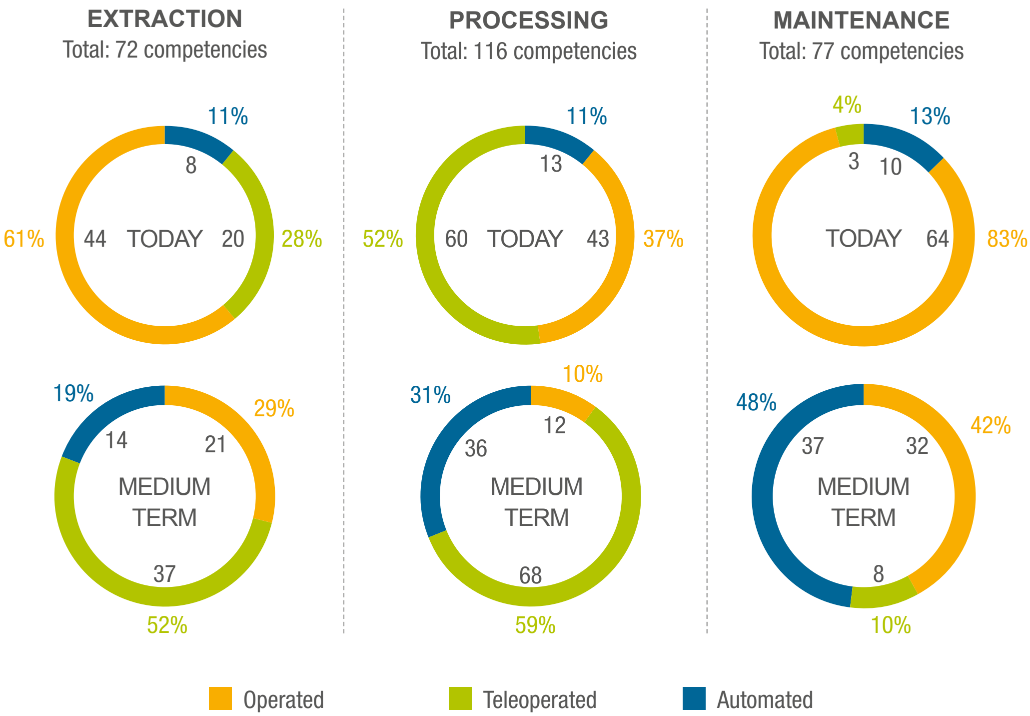
Evolution of competency requirements, in the medium term:

- 43% to 76% increase in competencies dealing with automation and teleoperation.
- 36% increase (from 83 to 113) in competencies associated to teleoperated technological level.
- 180% (from 31 to 87) increase in competencies associated to automated technological level.
- 57% decrease, approximately, (from 151 to 65 competencies) in operated functions.

[1] See page 92 of this report for further details on technical roundtables, companies involved, and their technical representatives.

Technological Level per Process

The following results were drawn from the 2017 - 2022 per-process analysis (Extraction, Cu Processing, and Maintenance):



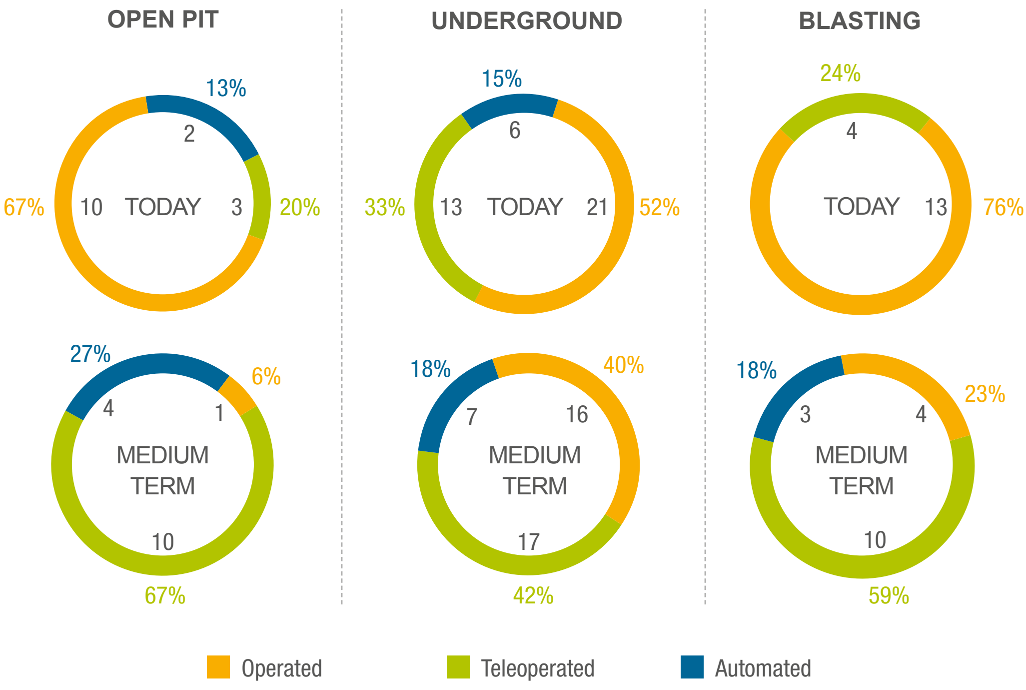
- Though the technical evolution could be more radical, nearly one third of competencies will undergo changes in the medium term.
- In Extraction, teleoperated competencies will show a 85% rise (from 20 to 37 competencies).
- In Processing and Maintenance, the greatest impact will be the transition to automation.

Technological Level per Subprocess

The following are the results obtained from the per-subprocess analysis conducted during specific technical roundtables:

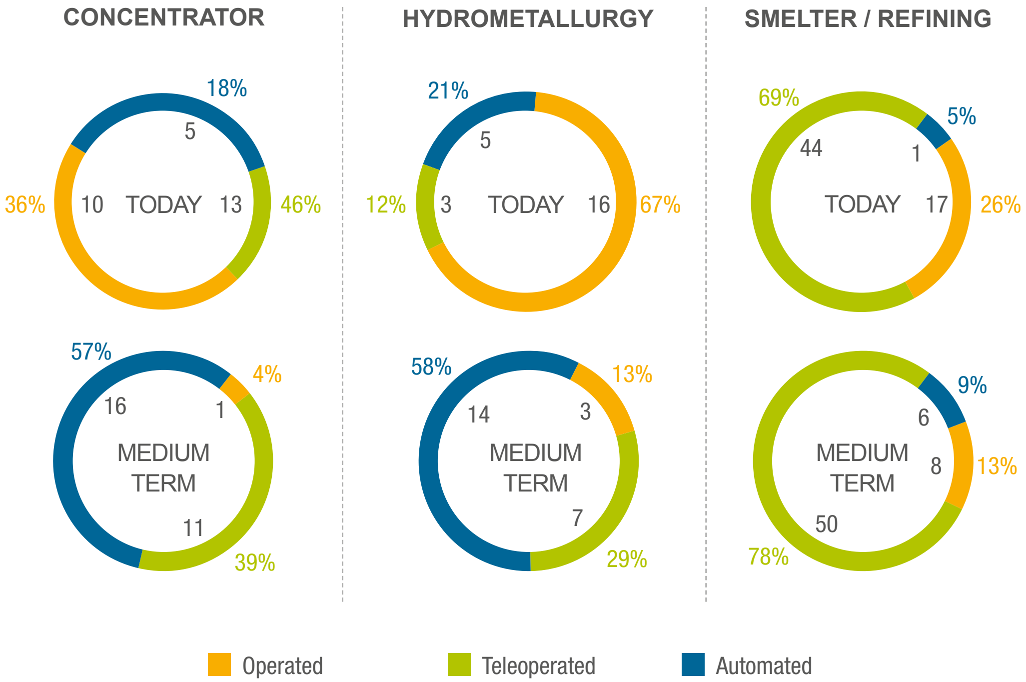
Extraction Subprocesses

- Open pit displays reveals a decrease in operated technological level from 10 to 1 WCU. Also, an increase from 3 to 10 WCUs in the teleoperated technological level.
- In Underground there is an increase of teleoperated technological level from 13 to 17 WCUs.
- In blasting, automation comes up as the technological alternative (3 WCUs). However, teleoperated shows the highest increase (4 to 10 WCUs).



Cu Processing Subprocesses

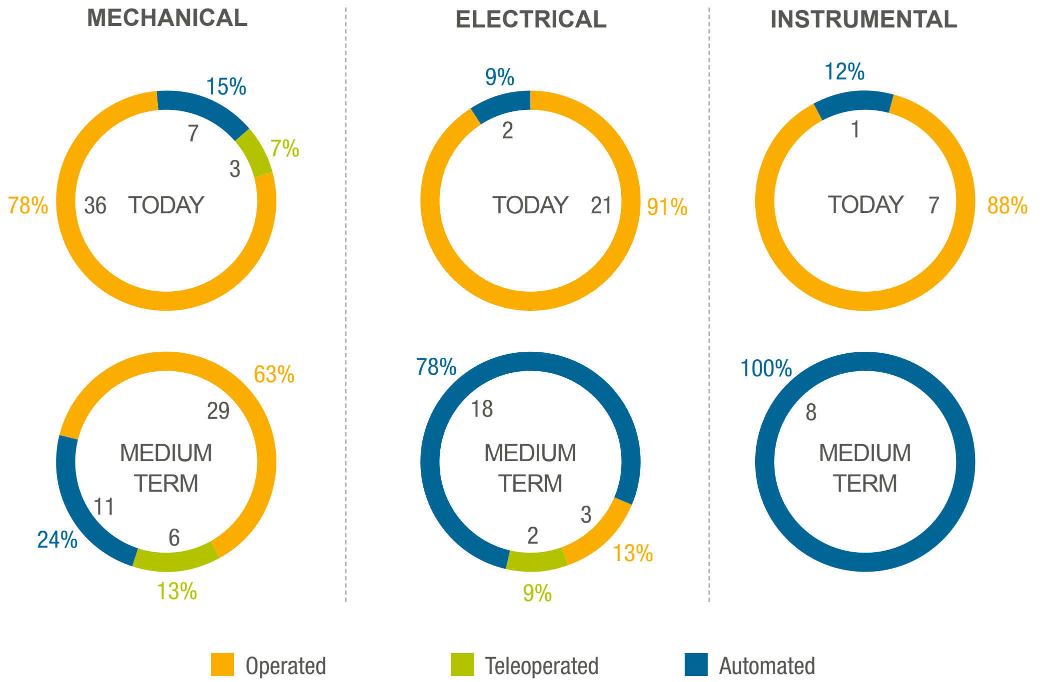
- Concentrator shows an increase in automation (5 to 16 WCUs). Same in Hydrometallurgy (5 to 14 WCUs).
- In smelter/refining the teleoperated technological option presents an increase, going from 44 to 50 WCUs.



Maintenance Subprocesses

- Mechanical Maintenance displays minor changes and the operated technological level drops from 36 to 29 WCUs.

- On the other hand, in electrical Maintenance (2 to 18 WCUs) and instrumental Maintenance (1 to 8 WCUs) a significant potential to incorporate automation can be observed.



Summary

A decrease is anticipated to occur in the operated competencies while teleoperated competencies in Extraction (85%) and automated mainly in Processing (180%) and Maintenance (270%) processes are foreseen to increase.

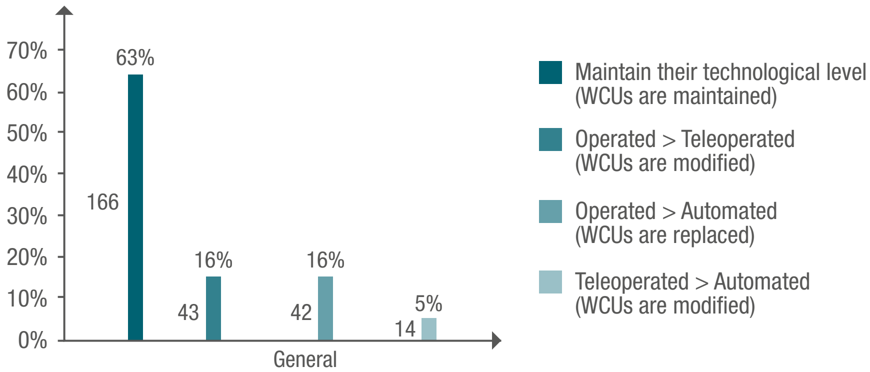
In Extraction, open pit is the process with the highest level of variation both in teleoperated, expected to increase, as well as in operated, estimated to drop significantly. Blasting is another subprocess showing variations and where automation will continue to grow.

As for Processing, hydrometallurgy is the subprocess anticipated to receive the hardest impact while teleoperation will increase and operated competencies will drop. The concentrator is the subprocess where automation will increase the most.

Finally, Maintenance's electrical and instrumental subprocesses will experience the most dramatic changes toward automation.

Changes in General Technological Level in a 5-Year Horizon

Based on the 265 competencies defined herein, the changes in technological level and the ensuing evolution of productive activities to be developed in the medium term were established. These would maintain their current condition moving to teleoperated or to automated. The chart below illustrates the results obtained from the analysis:



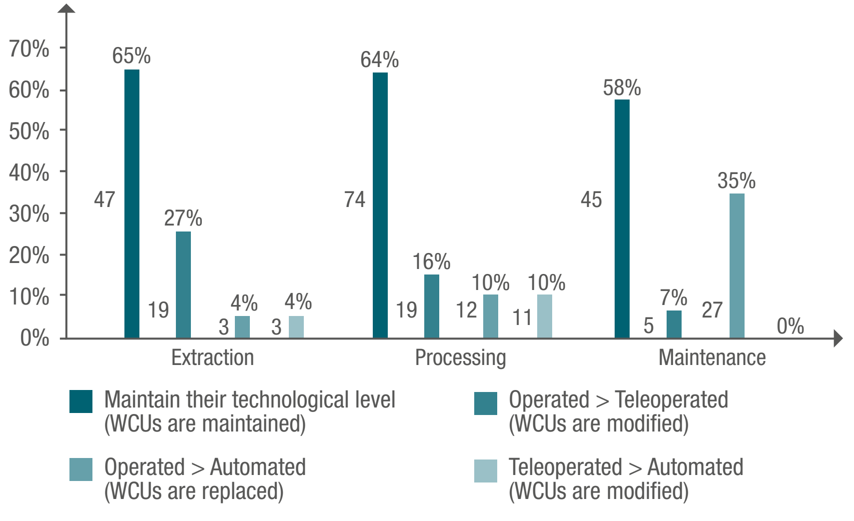
Based on the above results, a 37% of competencies is projected to be modified according to the technological changes currently undergone by the productive activities. That said, 16% of the above percentage implies going from an operated to a teleoperated technological level; another 16% will transition from an operated technological level to automated; and the remaining 5% will pass from teleoperated to automated.

Based on expert judgment, the bulk of the trend will move toward Automation, generating a 21% variation of total competencies.

These results also reported that 63% of competencies are projected to be maintained for the next 5 years, according to changes in the technological level.

Changes in Technological Level per Process

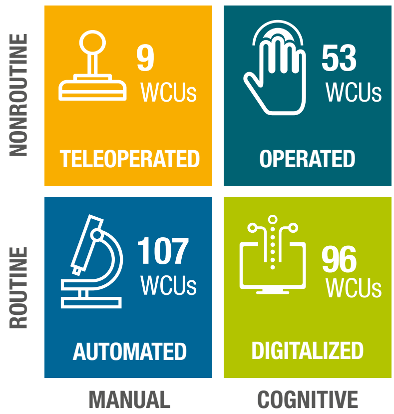
As seen in the chart below, an important portion of competencies are projected to be maintained in the medium term. Out of the 72 Extraction competencies analyzed, 35% of them are estimated to change due to the potential change of technological level (teleoperated to automated; operated to automated; and operated to teleoperated). As for Processing, 64% out of the 116 competencies analyzed will be maintained, as an important number of competencies are associated to already automated functions and thus their variation is calculated to be 36%. Finally, out of the 77 Maintenance competencies analyzed, 58% of them are deemed to be maintained while 42% might be modified as a result of potential changes in the technological level.



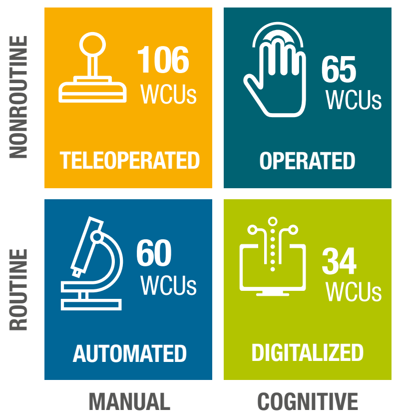
INTEGRATION OF TECHNOLOGICAL LEVEL AND DIGITAL TRANSFORMATION

The tendency identified by experts in different scenarios is that industry competencies will be changed and moved from a manual or teleoperated performance to an automated one. While the trend is already underway and digital transformation might potentially be more radical, experts are of the opinion that nearly a third of competencies will undergo changes and, the other two thirds, would be kept the unchanged within the five next years.

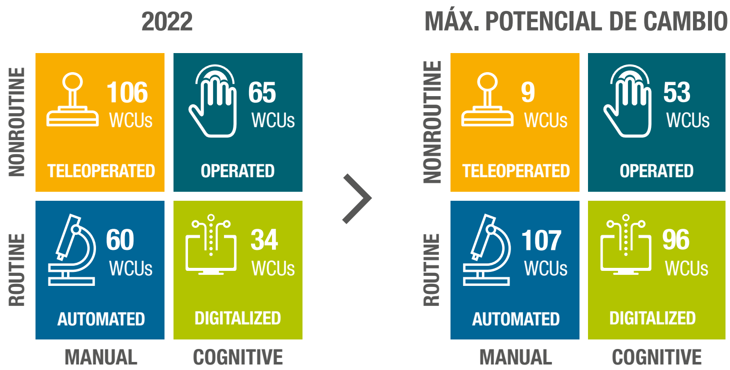
As stated at the outset of this study, the maximum theoretical change potential for competencies in the industry is observed to occur in the digital transformation process with a predominance of competencies destined to be automated or digitalized; that is, all those containing routine components will sustain changes, either by the arrival of automation or the inclusion of algorithms.



However, in a medium-term horizon and considering the technology available at that moment, a continuum is shown to exist going from manual to teleoperated operation and thence to automated. If this continuum if taken to the change potential analysis matrix, the competencies end up distributed as follows:

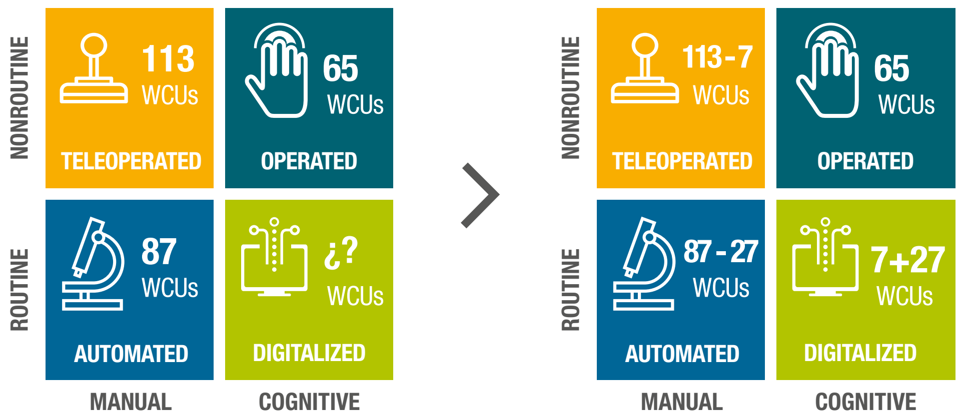


Finally, a continuum of development of digital transformation is proposed for the mining industry, with a first stage scheduled for 2022. It has been projected at maximum theoretical change potential in order to keep track of the direction of the transformation and confirm the hypothesis predicting that competencies will lean toward automation and digitalization (algorithms).



The level of progress the technological levels and digital transformation may finally achieve will depend on the exploitation conditions, geological characteristics, exploitation horizon, investment priorities, etc. each productive operation may present. For this reason, a non-homogenous evolution is expected where different technological scenarios will coexist. This means that all human capital development strategies should plan for a workforce capable of adapting to different technological scenarios.

In the course of this analysis, a thorough review of work competency units was performed; thus, and based on expert judgment, the competencies within the mining technology continuum destined to be digitalized (algorithm) were successfully identified as, at the beginning of this analysis, only the competencies meant to be maintained, teleoperated, or automated could be identified. On that basis, the following matrix was constructed:



CONCLUSIONS AND RECOMMENDATIONS

Based on the analysis conducted under the theoretical framework, the review of background information regarding the current technological state of the art, and the expert judgment received from key industry players, the foreseen impact of digital transformation and technological evolution on the different processes and subprocesses and, consequently, on their associated competencies was identified.

According to the research on the current technological status in the mining industry, some changes can be observed, such as big data, the use of autonomous trucks (a breakthrough in the Chilean mining industry), and process automation through integrated operations centers. The internet of things and additive manufacturing yet await further development.

As of 2017, Maintenance is the process with the largest number of manual operations. In Cu Processing, teleoperation has already been integrated.

A total of 86 new competencies (32% of MQF growth) are estimated to be required in the medium term (technological evolution).

- Maintenance would be subject to greater impact, where a transition from manual to automated is foreseen to occur, considering 32 new competencies (42%), especially those oriented to electrical and instrumental subprocesses.

- Extraction would go from manual to mostly teleoperated operation, with 23 new competencies to be required (32%). Open pit Extraction would be the most impacted subprocess. Finally, blasting is the subprocess with the highest growth of automation.

- Automation is seen to increase in Cu processing, considering the requirement of 31 new competencies (27%), focused on the concentrator subprocess. Hydrometallurgy would witness an important drop in operated competencies.

The maximum technological potential (digital transformation) anticipates that 80% of the competencies consider changes.

- Maintenance is the process projected to sustain the greatest impact, as 48% of competencies would be substituted. It is followed by Extraction with 43%.

- The competencies likely to be maintained are those associated to the functions of supervision, coordination and control in the different processes.

The evolution that competencies may experience in the present, medium and long term would not be continuous. A transition is expected from an operated to a teleoperated technological level and from teleoperated to Automated.

Reaching the maximum change potential (digital transformation) will depend on investment policies, strategy, and the specific conditions of each mine site.

This study is the starting point to begin measuring the transformation of work in mining, given the impact caused by the arrival of the fourth industrial revolution. The recommendation is to conduct a survey of the current technological level prevailing in each mine operation in Chile in order to identify their disposition/need to move into higher levels of automation and optimization. This will disclose the existing gaps with respect to the expected potential and define the actual human capital requirements with the competencies needed to face the technological absorption process.

ANNEXES

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MAXIMUM TECHNOLOGICAL LEVEL IDENTIFIED

Process	Subprocess	Equipment	Suppliers	Maximum technological level identified
Extraction	**Exploration and drilling**	Drilling machine	Sandvink	Teleoperated
			Atlas Copco	
			Boart Longyear	
	Open pit extraction	Drilling machine	CAT	Teleoperated
			Sandvik	
			Atlas Copco	
			Komatsu	
		Shovels	CAT	Manual operation
			Sandvik	
			Liebherr	
		Front loader	CAT	Manual operation
			Komatsu	
		Trucks	CAT	Autonomous
			Komatsu	
		Bulldozer	CAT	Manual operation
			Komatsu	
			Liebherr	
		Dispatch system	CAT	Monitoring, visualization
			Modular	
			Jiwsaw	
		Safety equipment	Modular	Monitoring, visualization
		Satellite positioning, GPS	Komatsu	Monitoring, visualization
		Equipment vital signs	CAT	Monitoring, visualization
			Komatsu	

Process	Subprocess	Equipment	Suppliers	Maximum technological level identified
Extraction		Gyratory crusher	Metso	Automated
			Sandvik	
			FLSmidth	
		Jaw crusher	Metso	Semiautomated
			Sandvik	
			FLSmidth	
		Cone crusher	Metso	Automated
			Sandvik	
		Control system	Sandvik	Automated
	Underground extraction	LHD	CAT	Teleoperated
			Komatsu	
			Atlas Copco	
			Sandvik	
		Production jumbo	Komatsu	Teleoperated
			Atlas Copco	
			Sandvik	
		Rock breaker	Sandvik	Teleoperated
			Atlas Copco	
			BTI	
			Brokk	
		Belts	Good year	Monitoring, visualization
			Phoenix	
			Contitech	
			Bridgestone	
		Dumper	CAT	Manual operation
			Sandvik	
			Komatsu	
			Atlas Copco	

Process	Subprocess	Equipment	Suppliers	Maximum technological level identified
Processing		Locomotive	Ferroestatal	Semiautonomous
			Kiruna	
	Blasting	Factory truck	Enaex	Teleoperated
			Orica	
	Concentrate process	Rod mill	Metso	Automated
		Ball mill	Metso	Automated
			FLSmidth	
		SAG mill	Metso	Automated
			FLSmidth	
		Screen	Metso	Manual operation
			Sandvik	
			Tyler	
			Ludowici	
		Pebbles crusher	Metso	Automated
			FLSMidth	
		AG	Metso	Automated
			FLSmidth	
			Outotec	
		HPGR	ABB	Semiautonomous
			Metso	
			FLSmidth	
		Cells	Metso	Automated
			FLSmidth	
			Outotec	
		Vertical mill	Metso	Automated
			FLSmidth	
		Hydrocyclones	Weir	Automated
			FLSmidth	
		Column cells	Metso	Automated
			FLSmidth	
			Outotec	

Process	Subprocess	Equipment	Suppliers	Maximum technological level identified
Processing		Floatation cells	Metso	Automated
			FLSmidth	
			Outotec	
		Thickener	FLSmidth	Automated
			Outotec	
			Delkor	
		Vacuum filter	Outotec	Automated
			Delkor	
	Hydrometallurgy	Belts	Metso	Automated
			Aplik	
			Sandvik	
		Stacks	Aplik	Monitoring, visualization
		Radial stacker	Metso	Automated
			FAM	
			Sandvik	
		Bucket wheel excavator	FAM	Manual operation
			FLSmidth	
			Sandvik	
		Electrolytic cells (EW)		
		Electrolytic circuit	Outotec	Monitoring, visualization
			Aplik	
		Cathode washing machine	Outotec	Automated
		Cathode stripping machine	MIRS	Automated
			Outotec	
			Aplik	

SOME VISIONS CAPTURED IN THE INTERVIEWS

Operators:

- *"We have high-technology equipment. Bid conditions specify these must be automatic, high-technology machines. They must handle bars automatically in order to minimize the risk of accidents caused by slimes. This is defined by the company. They specify the equipment must be as safe as possible. There are less people working on site. They employ a drilling machine operator and an assistant to carry out the drillings who work with telecommand control; nothing is lost; it is more expensive, but higher safety is worth the extra cost".*
- *"Heavy-duty earthmoving equipment (loaders, retroexcavators, bulldozers, column cells, and distributed control systems that enable the plant to be operated automatically). There is an important level of automation".*
- *"From my point of view, we have very little technology. Mining has done little progress in the way of technology; not many changes since the 90s; little innovation".*
- *"Change the mindset to move to automated or telecommanded operation".*
- *"All are manually operated, all ground and electrical equipment is manual and, therefore, less safe. Next year we'll be working with telecommanded units".*
- *"Some manual processes can be automated but in all cases a lot of on-site supervision is needed".*
- *"The mine has high-technology equipment; not much variation in the type of technology being used in the last five years but the software that runs the equipment has changed a lot. You can monitor the operation conditions and that allows operators to improve their performance".*
- *"The changes will be seen in the future. This has been the same for the last five years; improvements have been made but the process is the same".*
- *"The cultural change is the hardest challenge; people don't like. We talk to people, we show them the benefits this brings along, we seek to improve their jobs and reduce their workload (less wear-out). When we explain the objective, people assume it".*
- *"I think five years is very little time for that, considering how the mine is today. I think that new technologies are going to be incorporated to protect workers and ensure more safety for them and protect people from exposure to risky jobs, physical injuries and serious accidents. Moving forward we should have autonomous equipment but, for now, they are focused on safety".*

Proveedores:

- *"Before an autonomous or automated process can be implemented, a training period on the machines is required; the equipment must be programmed and fed with information on where they will be circulating, their routes, and how to do their jobs. Once that is done, the equipment will be ready to operate and accomplish the missions indicated. The only thing the operator has to do is monitor the execution of those missions. We have a system that reads the number of missions being executed by a unit and as they are completed it moves to the next mission. The equipment knows how it works and can complete the whole routine on its own".*
- *"Smart equipment come with all systems incorporated; the operations room is implemented and it is ready to work".*
- *"Most units, from the least to the most advanced, are automated or on their way to*
- *automation. Also, all our machines are operated from tablets and the operator feeds the system all through the shift".*

- *"Everything points at autonomy of processes, trucks, shovels, etc. That is, smart equipment operating autonomously".*
- *"A radical change is coming; changes will be seen in two or three years. The trend is moving to automation: deploy people from the mining process and work with other profiles in order to control de mine from a distance, ensuring more safety, health, productivity, and efficiency".*
- *"In five years everything will be virtual reality, massive digitalization (eg, application-controlled switches). Increase wireless technology, electrification technologies. Virtual reality enables me to explore equipment free of intervention. Using information in real time is another challenge ahead".*

SPEAKERS AND PARTICIPANTS IN WORKSHOPS

Facilitator	Position	Function
Diego Richard	Former Director Sectoral Initiative Program	Workshop host
Rafael Pizarro	Leader Standard Work	MQF speaker
Eduardo Soto	Project Manager	Participant coordinator
Paulina Peña	Project Manager	Study expert
Carolina Águila	Project Manager	Moderator/roundtable facilitator
Patricio Balmaceda	Project Manager	Roundtable facilitator
Felipe Dosal	Consultant	Roundtable facilitator
Guillermo Álvarez	Consultant	Roundtable facilitator
Angela Ventura	Consultant	Roundtable facilitator

Name	Company	Proceso
Cristian Araya	AMSA	Open pit extraction
Juan Pizarro	AMSA	Open pit extraction
Pablo Moore	Modular Mining	Open pit extraction
Ismael Gottreux	Orica	Underground extraction
Manuel Espejo	FLSMidth	Mechanical Maintenance
Francisco Rivera	Komatsu	Mechanical Maintenance

Name	Empresa	Process
Francisco Reyes	BASF	Hydrometallurgy
Silvana Zeballos	FESTO	Concentrator
Diego Rodríguez	FESTO	Concentrator
Patricio Rojas	METSO	Concentrator
Jorge del Castillos	Codelco	Smelter/Refining
Marco Henríquez	University of Santiago	Electrical/instrumental Maintenance

COMPETENCY DISTRIBUTION PER PROCESS AND SUBPROCESS

Digital Transformation

The following is a detailed list of competencies distributed per process and subprocess, according to the maximum potential of digital transformation:

Competencies Extraction process: Open pit Extraction subprocess

Maximum potential of automation (Routine/Manual quadrant)

- Operate high-tonnage truck.
- Prepare and make ready area with crawler-mounted tractor.
- Conduct open-pit drillings.
- Prepare and make ready area with pneumatic tractor.
- Reduce boulders and soils with mobile rock breaker.
- Transport electrical equipment with autonomous generator.
- Transport equipment within mine facilities.
- Drill boulders.

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Operate production excavator.
- Load material with mobile front loader.
- Load ore with shovels.
- Irrigate worksite and assist operations.
- Shape and refine worksite.

Maximum potential of teleoperation (Nonroutine/Manual quadrant)

No competencies assigned to this quadrant.

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Coordinate mine dispatch system.
- Supervise open-pit extraction process.

Competencies Extraction process: Underground Extraction subprocess

Maximum potential of automation (Routine/Manual quadrant)

- Operate LHD remotely.
- Operate mobile rock breaker.
- Operate ore conveyor belts.
- Control ore transfer remotely.
- Install reinforcement bolts, cables, and meshes.

- Conduct basic piping repairs.
- Transport explosives inside mine.
- Operate mechanical scaler.
- Operate concrete pump.
- Operate low-profile mixer equipment.
- Operate telescopic equipment.
- Execute scaling.
- Execute manual rock drilling in underground mine.
- Install reinforcement frames.
- Transport ore on high-tonnage trucks inside mine.
- Operate stationary rock breaker.
- Operate transfer bin.

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Operate reinforcement equipment (shotcrete).
- Prepare development blasting.
- Control ventilation inside mine.
- Operate ore crushing system inside mine.
- Execute secondary blasting.
- Control water and air production support service.
- Operate jumbo.
- Operate LHD in production.
- Keep record of productive and operational status of operation points.
- Control crushing plant from control room.
- Unblock ore passes with explosives.
- Prepare and execute caving blasting.
- Take samples from extraction points.
- Operate jumbo (secondary reduction).
- Operate screen and feeder systems.

Maximum potential of teleoperation (Nonroutine/Manual quadrant)

- Repair production drifts.
- Repair production grizzly.
- Install ventilation, drainage, compressed-air network, and water services in underground mine.
- Execute welding and oxy-fuel cutting.

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Coordinate preparation processes in underground mine.
- Supervise underground extraction process.
- Monitor underground extraction process.
- Coordinate development and service processes in underground mine.

Competencies Extraction process: Blasting subprocess

Maximum potential of automation (Routine/Manual quadrant)

- Load blasthole with autonomous equipment in blasting process, open-pit and underground mines.
- Operate mini front loader in blasting process.
- Prepare conditions to load blastholes with factory truck in blasting process, open-pit mine.
- Operate underground automated loading truck in blasting process, underground mine.
- Operate underground manual loading truck in blasting process, underground mine.
- Operate blasthole stemming equipment in blasting process.

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Manage supply and distribution of explosives in magazine, open-pit and underground mines.
- Design blasting sequence in open-pit and underground mines.
- Load blastholes manually in blasting process, open-pit and underground mines.
- Schedule blasting sequence in open-pit and underground mines.
- Operate factory truck in blasting processes, open-pit mine.
- Operate explosives truck in blasting processes, open-pit and underground mines.
- Operate boom truck in blasting process, open-pit and underground mines.
- Prepare blasthole in blasting process, open-pit and underground mines.

Maximum potential of teleoperation (Nonroutine/Manual quadrant)

No competencies assigned to this quadrant.

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Ensure blasthole conditions in blasting process, open-pit and underground mines.
- Supervise blasting process in open-pit mine.
- Supervise blasting process in underground mine.

Competencies Maintenance process: Mechanical Maintenance subprocess

Maximum potential of automation (Routine/Manual quadrant)

- Maintain mechanical brakes.
- Maintain lubrication systems.
- Maintain pneumatic systems.
- Assist in the mounting and dismounting of conveyor belts.
- Assist in conveyor belt vulcanization.
- Mount and dismount conveyor belts.
- Maintain centrifugal pumps.
- Maintain conveyor belts and feeders.
- Provide basic maintenance service to conveyor belts and feeders.
- Maintain diesel engines.

- Maintain steel piping systems.
- Maintain polymer piping systems.
- Maintain transmission systems.
- Maintain hydraulic systems.
- Maintain valves.
- Maintain fans.
- Monitor mining equipment performance with electronic tools.
- Perform electrical testing of magnetic particles.
- Perform mechanical testing of thickness and dimensional control.
- Perform mechanical testing of lubricants.
- Perform X-ray mechanical testing.
- Perform ultrasound mechanical testing.
- Perform vibration mechanical testing.
- Perform mechanical electrical harmonics testing.
- Provide basic maintenance service to stationary equipment.
- Provide basic mechanical maintenance service to mobile equipment.
- Perform arc welding (conventional), MIG & TIG.
- Perform arc welding (conventional).
- Perform conveyor belt vulcanization.

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Maintain temperature regulation system.
- Operate bridge crane (mechanical Maintenance).
- Perform analysis and interpretation of NDT tests.
- Diagnose and replace positive displacement pumps.
- Maintain wear-out elements.
- Perform mechanical hardness testing.

Maximum potential of teleoperation (Nonroutine/Manual quadrant)

No competencies assigned to this quadrant.

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Coordinate and supervise conveyor belt vulcanization/replacement tasks.
- Maintain hydraulic systems (specialist).
- Change parameters of mining equipment motors with electronic tools.
- Coordinate NDT testing activities.
- Coordinate maintenance activities.
- Diagnose and replace positive displacement pumps (specialist).
- Maintain mechanical brakes (specialist).
- Maintain diesel engines (specialist).
- Maintain transmission systems (specialist).
- Maintain pneumatic systems (specialist).
- Maintain valves (specialist).

Competencies Maintenance process: Instrumental Maintenance process

Maximum potential of automation (Routine/Manual quadrant)

- Maintain variable frequency drives.

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Maintain data transmission network systems.
- Diagnose pneumatic control systems.
- Maintain field instrumentation devices.
- Maintain analogue and digital instrumentation systems.
- Maintain process controllers.
- Maintain control systems.

Maximum potential of teleoperation (Nonroutine/Manual quadrant)

No competencies assigned to this quadrant.

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Maintain ionizing equipment.

Competencies Maintenance process: Electrical Maintenance subprocess

Maximum potential of automation (Routine/Manual quadrant)

- Maintain switches and disconnectors.
- Maintain low, medium, and high voltage systems.
- Maintain switchboard, power, and control panels.
- Maintain electrical motors and generators.
- Maintain mining equipment electrical motors and generators.
- Maintain switchboard, power, and control panels (specialist).
- Provide basic general electrical-instrumental Maintenance.

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Maintain low, medium, and high voltage systems (specialist).
- Monitor mining equipment performance with electronic tools.
- Change parameters of mining equipment motors with electronic tools.
- Maintain switches and disconnectors (specialist).
- Maintain electric power distribution lines.
- Maintain electric power distribution lines (specialist).
- Maintain protections in electrical power systems (specialist).
- Maintain mining equipment starting systems.
- Maintain medium-voltage transformers.

- Maintain medium-voltage transformers (specialist).
- Maintain medium-voltage rectifiers (specialist).

Maximum potential of teleoperation (Nonroutine/Manual quadrant)

- Maintain electrical motors and generators.
- Maintain mining equipment motors and generators (specialist).

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Channel and lay medium-voltage lines.
- Channel and lay medium-voltage lines (specialist).
- Maintain energy meters (specialist).

Competencies Processing process: Concentrate subprocess

Maximum potential of automation (Routine/Manual quadrant)

- Operate (on site) Mo concentrate packing, loading, and dispatching processes.
- Operate equipment for long-distance slurry transport.
- Operate thickeners.
- Operate (on site) Mo filtering processes.
- Operate on site concentrate thickening processes (Cu & Mo)
- Operate tailings transport, placement, and water recovery equipment.
- Operate pressure-filtering units.

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Operate regrinding and grading equipment.
- Operate crushing plant equipment.
- Operate and control moisture filtering processes.
- Control Mo concentrate packing, loading, and dispatch process.
- Control tailings transport and H2O recovery processes.
- Operate (on site) Mo flotation process.
- Operate flotation cells.
- Operate flotation columns.
- Operate conventional grinding plant equipment.
- Operate SAG mill equipment.
- Receive and handle reagents.

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Add grinding media.

Competencias que se mantienen (Cuadrante No Rutinario/Cognitivo)

- Control Mo concentrate filtering process.
- Control SAG grinding process.
- Supervise concentrate processing.

- Control concentrate thickening process (Cu & Mo).
- Control crushing plant from control room.
- Control Mo flotation process.
- Control cell flotation process.
- Control column flotation process.
- Control conventional grinding process.

Competencies Processing process: Hydrometallurgy subprocess

Maximum potential of automation (Routine/Manual quadrant)

- Perform cathode stripping.
- Operate electro-winning cells.
- Operate bucket wheel excavator.
- Inspect electrowinning cells.
- Install heap irrigation system.
- Operate leaching process on site.
- Operate sintering plant equipment.
- Operate crushing plant equipment.
- Operate SX equipment plant.
- Operate spreader.
- Operate bridge crane (EW).

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Control cathode dispatch.
- Control ore sintering plant.
- Control leaching process.
- Coordinate electrode replacement.

Maximum potential of teleoperation (Nonroutine/Manual quadrant)

- Stockpile material for leaching.
- Change anodes and cathodes.

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Control EW processes from control room.
- Monitor electrolyte conditions.
- Supervise leaching and SX processes.
- Control crushing plant (oxide) from control room.
- Control SX plant from control room.
- Supervise hydrometallurgy, dry area process.
- Supervise electrowinning process.

Competencies Processing process: Smelting/Refining subprocess

Maximum potential of automation (Routine/Manual quadrant)

- Bleed molten liquids, flash furnace.
- Operate lug-cutting machine.
- Operate starting cathode preparation machine.
- Prepare casting ladle.
- Operate miniloader.
- Operate forklift.
- Heat furnaces.
- Operate anode dispatch.
- Operate flash furnace cooling systems.
- Operate acid dispatch by land (on tine).
- Operate water supply.
- Control compressed-air production.
- Inspect electrowinning cells.
- Operate anode slimes drying, disaggregation, and dispatch.
- Operate pressure-filtering units.
- Operate electrowinning cells.
- Operate cathode washing machine.
- Operate scrap washing machine.
- Operate anode preparation machine.
- Operate anodic slimes leaching process.

Maximum potential of digitalization (Routine/Cognitive quadrant)

- Transport smelted, heavy material with bridge crane.
- Handle smelting tilting furnace.
- Monitor electrolyte conditions.
- Opera casting equipment.
- Operate mobile rock breaker.
- Supply load to smelter.
- Control copper concentrate drying.
- Operate smelting - converting tilting furnaces.
- Operate refining tilting furnaces.
- Operate flash furnace.
- Operate acid plant.
- Operate weak acid treatment plant.
- Operate gas treatment plant.
- Operate fuel supply.
- Operate oxygen plant.
- Operate air plant.
- Control scrap washing, tilting furnace.
- Control smelting-converting in furnaces.
- Control anodic copper production.
- Control anode bar casting.

- Control gas handling.
- Control weak acid treatment.
- Control sulfuric acid production.
- Control oxygen-nitrogen production.
- Control cathode dispatch.
- Control anodic slimes treatment plant from control room.
- Control refining process from control room.
- Perform cathode stripping.
- Operate bridge crane (EW).
- Change anodes and cathodes.

Maximum potential of teleoperation (Nonroutine/Manual quadrant)

No competencies assigned to this quadrant.

Competencies to be maintained (Nonroutine/Cognitive quadrant)

- Supervise compressed-air production.
- Maintain smelting furnace refractories.
- Supervise sulfuric acid production.
- Manufacture molds and copper pieces.
- Control white metal conversion into blister copper in CPS furnaces.
- Coordinate smelting-converting services.
- Supervise smelting-converting furnaces.
- Supervise anodic copper production.
- Supervise anode casting.
- Supervise oxygen production.
- Supervise weak acid treatment.
- Supervise gas handling operation.
- Supervise electrolytic refining process.

Technological Level

The following is a detailed list of competencies distributed per process and subprocess, according to the technological level expected by 2022.

Competencies Extraction process: Open-pit Extraction subprocess

Automation (Routine/Manual quadrant)

- Operate high-tonnage truck.
- Reduce boulders and soils with mobile rock breaker.
- Drill boulders.
- Coordinate mine dispatch system.

Digitalization (Routine/Cognitive quadrant)

No competencies assigned to this quadrant.

Teleoperation (Nonroutine/Manual quadrant)

- Operate production excavator.
- Prepare and make ready area with pneumatic tractor.
- Irrigate worksite and assist operations.
- Shape and refine worksite MO.
- Prepare and make ready area with crawler-mounted tractor.
- Transport electrical equipment with autonomous generator.
- Transport equipment within mine facilities.
- Load material with mobile front loader.
- Load ore with shovels
- Conduct open-pit drillings.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

- Supervise open-pit extraction process.

Underground Extraction subprocess

Automation (Routine/Manual quadrant)

- Operate remotely.
- Operate mobile rock breaker.
- Install reinforcement frames, according to legal regulations in place.
- Operate LHD in production.
- Operate ore conveyor belts.
- Operate stationary rock breaker.
- Operate transfer bin.

Digitalization (Routine/Cognitive quadrant)

- Unblock ore passes with explosives.

Teleoperation (Nonroutine/Manual quadrant)

- Control ore transfer remotely.
- Operate ore crushing system inside mine.
- Install reinforcement bolts, cables, and meshes.
- Operate reinforcement equipment (shotcrete).
- Operate mechanical scaler, according to legal regulations in place.
- Operate telescopic equipment.
- Execute manual rock drilling in underground mine.
- Execute secondary blasting.
- Prepare development blasting.
- Control ventilation inside mine.
- Operate jumbo.
- Transport ore on high-tonnage trucks inside mine.
- Monitor underground extraction process.
- Control crushing plant from control room.
- Operate jumbo units (secondary reduction).
- Operate screen and feeder systems.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

- Coordinate preparation processes for underground mine, according to legal regulations in place.
- Coordinate development and service processes, underground mine, according to legal regulations in place.
- Supervise underground extraction process.
- Repair production drifts.
- Repair production grizzly.
- Execute welding and oxy-fuel cutting.
- Transport explosives inside mine.
- Operate concrete pump, according to legal regulations in place.
- Operate low-profile mixer, according to legal regulations in place.
- Execute scaling.
- Conduct basic piping repairs.
- Install ventilation, drainage, compressed-air networks, and water services in underground mine, according to legal regulations in place.
- Control water and air production support service.
- Keep record of productive and operational status of operation points.
- Prepare and execute caving blasting.
- Take samples from extraction points.

Blasting subprocess

Automation (Routine/Manual quadrant)

- Manage explosive supply and distribution in magazine in open-pit and underground mines, according to current safety regulations
- Design blasting sequence in open-pit and underground mines, according to current safety regulations.
- Schedule blasting sequence in open-pit and underground mines, according to current safety regulations.

Digitalization (Routine/Cognitive quadrant)

No competencies assigned to this quadrant.

Teleoperation (Nonroutine/Manual quadrant)

- Ensure blasthole conditions in blasting process, open-pit and underground mines, according to current safety regulations.
- Operate underground automated loading truck in blasting process, underground mine, according to current safety regulations.
- Operate underground manual loading truck in blasting process, underground mine, according to current safety regulations.
- Operate factory truck in blasting process, open-pit mine.
- Operate boom truck in blasting process, open-pit and underground mines, according to current safety regulations.
- Operate explosives truck in blasting process, open-pit and underground mines, according to current safety regulations.
- Operate blasthole stemming equipment in blasting process, according to current safety regulations.
- Operate mini front loader in blasting process, according to current safety regulations.
- Prepare conditions to load blasthole with factory truck, in blasting process, open-pit mine.
- Load blastholes manually in blasting process, open-pit and underground mines, according to current safety regulations.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

- Load blastholes with autonomous equipment, in blasting process, open-pit and underground mines, according to current safety regulations.
- Prepare blasthole in blasting process, open-pit and underground mines, according to current safety regulations.
- Supervise blasting process in open-pit mine, according to current safety regulations.
- Supervise blasting process in underground mine, according to current safety regulations.

Competencies Maintenance process: Mechanical Maintenance process

Automation (Routine/Manual quadrant)

- Monitor mining equipment performance with electronic tools.
- Perform analysis and interpretation of NDT tests.
- Perform electrical testing of magnetic particles.
- Perform mechanical testing of lubricants.
- Perform X-ray mechanical testing.
- Perform ultrasound mechanical testing.
- Perform vibration mechanical testing.
- Perform mechanical electrical harmonics testing.
- Perform arc welding (conventional), MIG & TIG.

Digitalization (Routine/Cognitive quadrant)

- Coordinate NDT testing activities.
- Coordinate maintenance activities.
- Coordinate and supervise conveyor belt vulcanization/replacement tasks.
- Diagnose and replace positive displacement pumps.
- Perform mechanical hardness testing.

Teleoperation (Nonroutine/Manual quadrant)

- Maintain wear-out elements.
- Operate bridge crane (mechanical Maintenance).
- Perform conveyor belt vulcanization.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

- Assist in the mounting and dismounting of conveyor belts.
- Assist in conveyor belt vulcanization.
- Diagnose and replace positive displacement pumps (specialist).
- Mount and dismount conveyor belts.
- Maintain centrifugal pumps.
- Maintain conveyor belts and feeders.
- Provide basic maintenance service to conveyor belts and feeders.
- Maintain mechanical brakes.
- Maintain mechanical brakes (specialist).
- Maintain diesel motors.
- Maintain diesel motors (specialist).
- Maintain lubrication systems.
- Maintain steel piping systems.
- Maintain polymer piping systems.
- Maintain temperature regulation systems.
- Maintain transmission systems.
- Maintain transmission systems (specialist).

- Maintain hydraulic systems.
- Maintain hydraulic systems (specialist).
- Maintain pneumatic systems.
- Maintain pneumatic systems (specialist).
- Maintain valves.
- Maintain valves (specialist).
- Maintain fans.
- Change parameters of mining equipment motors with electronic tools.
- Perform mechanical testing of thickness and dimensional control.
- Provide basic maintenance service to stationary equipment.
- Provide basic mechanical maintenance service to mobile equipment.
- Perform arc welding (conventional).

Instrumental Maintenance subprocess

Automation (Routine/Manual quadrant)

- Diagnose pneumatic control systems..

Digitalization (Routine/Cognitive quadrant)

- Maintain field instrumentation devices.
- Maintain ionizing equipment.
- Maintain analogue and digital instrumentation systems.
- Maintain data transmission network systems.
- Maintain process controllers.
- Maintain control systems.
- Maintain variable frequency drives.

Teleoperation (Nonroutine/Manual quadrant)

No competencies assigned to this quadrant.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

No competencies assigned to this quadrant.

Electrical Maintenance subprocess

Automation (Routine/Manual quadrant)

- Monitor mining equipment performance with electronic tools.
- Change parameters of mining equipment motors with electronic tools.

Digitalization (Routine/Cognitive quadrant)

- Maintain switches and disconnectors.
- Maintain switches and disconnectors (specialist).
- Maintain electric power distribution lines (specialist).
- Maintain energy meters (specialist).
- Maintain electrical motors and generators
- Maintain electrical motors and generators (specialist).
- Maintain mining equipment electrical motors and generators.
- Maintain mining equipment electrical motors and generators (specialist).
- Maintain protections in electrical power systems (specialist).
- Maintain low, medium, and high voltage systems.
- Maintain low, medium, and high voltage systems (specialist).
- Maintain mining equipment starting systems.
- Maintain switchboard, power, and control panels.
- Maintain switchboard, power, and control panels (specialist).
- Maintain medium-voltage transformers.
- Maintain medium-voltage transformers (specialist).
- Maintain medium-voltage rectifiers (specialist).

Teleoperation (Nonroutine/Manual quadrant)

- Maintain electric power distribution lines.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

- Channel and lay medium-voltage lines.
- Channel and lay medium-voltage lines (specialist).
- Provide basic general electrical-instrumental Maintenance.

Competencies Processing process: Concentrate subprocess

Automation (Routine/Manual quadrant)

- Control concentrate thickening process (Cu & Mo).
- Control Mo flotation process.
- Control cell flotation process.
- Control column flotation process.
- Operate (on site) Mo concentrate packing, loading, and dispatch process.
- Operate (on site) Mo filtering process.
- Operate (on site) Mo flotation process.
- Operate flotation cells.
- Operate flotation columns.
- Operate tailings transport, placement, and water recovery equipment.
- Operate thickeners.
- Operate pressure-filtering units.
- Operate and control moisture filtering process.
- Supervise concentrate processing.

Digitalization (Routine/Cognitive quadrant)

- Control tailings transport and H2O recovery processes.
- Control Mo concentrate packing, loading, and dispatch process.

Teleoperation (Nonroutine/Manual quadrant)

- Add grinding media.
- Control crushing plant from control room.
- Control Mo concentrate filtering process.
- Control conventional grinding process.
- Control SAG grinding process.
- Operate on site concentrate thickening process (Cu & Mo).
- Operate regrinding and grading equipment.
- Operate equipment for long-distance slurry transport.
- Operate crushing plant equipment.
- Operate conventional grinding plant equipment.
- Operate SAG mill plant equipment.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

- Receive and handle reagents.

Hydrometallurgy subprocess

Automation (Routine/Manual quadrant)

- Control cathode dispatch.
- Control ore sintering plant.
- Control crushing (oxide) plant from control room.
- Control SX plant from control room.
- Control leaching process.
- Control EX processes from control room.
- Coordinate electrode replacement.
- Perform cathode stripping.
- Monitor electrolyte conditions.
- Operate electrowinning cells.
- Operate leaching process on site.
- Operate sintering plant equipment.
- Operate crushing plant equipment.
- Operate SX plant equipment.

Digitalization (Routine/Cognitive quadrant)

- Operate bridge crane (EW).
- Operate bucket wheel excavator.

Teleoperation (Nonroutine/Manual quadrant)

- Stockpile material for leaching.
- Inspect electrowinning cells.
- Install heap irrigation system.
- Operate spreader.
- Change anodes and cathodes.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

- Supervise hydrometallurgy, dry area process.
- Supervise electrowinning process.
- Supervise leaching and SX process.

Smelting/Refining subprocess

Automation (Routine/Manual quadrant)

- Operate oxygen plant.
- Control oxygen-nitrogen production.
- Control compressed-air production.
- Supervise oxygen production.

- Supervise compressed-air production.
- Perform cathode stripping.

Digitalization (Routine/Cognitive quadrant)

No competencies assigned to this quadrant.

Teleoperation (Nonroutine/Manual quadrant)

- Bleed molten liquids, flash furnace.
- Operate miniloader.
- Operate mobile rock breaker.
- Operate forklift.
- Heat furnaces.
- Supply load to smelter.
- Control copper concentrate drying.
- Operate anode dispatch.
- Operate flash furnace cooling system.
- Operate smelting-converting tilting furnaces.
- Operate refining tilting furnaces.
- Operate flash furnace.
- Operate acid dispatch by land (on site).
- Operate acid plant.
- Operate weak acid treatment plant.
- Operate gas treatment plant.
- Operate fuel supply.
- Operate water supplies.
- Operate air plant.
- Transport smelted, heavy material with bridge crane.
- Control smelting-converting in furnaces.
- Control anodic copper production.
- Control anode bar casting.
- Control gas handling.
- Control weak acid treatment.
- Control sulfuric acid production.
- Supervise smelting-converting furnaces.
- Supervise anodic copper production.
- Supervise anode casting.
- Supervise weak acid treatment.
- Supervise sulfuric acid production.
- Supervise gas handling operation.
- Control cathode dispatch.
- Control anodic slimes treatment plant from control room, according to legal regulations in place.
- Control refining process from control room, according to legal regulations in place.
- Inspect electrowinning cells.
- Monitor electrolyte conditions.

- Operate electrowinning cells.
- Operate thickeners.
- Operate lug-cutting machine, according to legal regulations in place.
- Operate cathode washing machine, according to legal regulations in place.
- Operate scrap washing machine, according to legal regulations in place.
- Operate anode preparation machine, according to legal regulations in place.
- Operate starting cathode preparation machine, according to legal regulations in place.
- Operate anodic slimes leaching process, according to legal regulations in place.
- Operate bridge crane (EW).
- Operate anode slimes drying, disaggregation, and dispatch, according to legal regulations in place.
- Operate pressure-filtering units.
- Change anodes and cathodes.
- Supervise electrolytic refining process, according to legal regulations in place.

Operated/Analytical thinking (Nonroutine/Cognitive quadrant)

- Operate casting equipment.
- Prepare casting ladle.
- Maintain smelting furnace refractories.
- Manufacture molds and copper pieces.
- Control white metal conversion into blister copper in CPS furnaces.
- Control scrap washing, tilting furnace.
- Handle smelting tilting furnace.
- Coordinate smelting-converting services.

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