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A STUDY: NEW TRENDS IN MINING INDUSTRY

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Abstract In the coal mining industry, advancement is an important tool for improving efficiency levels, improving efficiency, and solving growing social and environmental considerations among populations and governments. Technological progress has also been crucial in enabling young mines to be exploited in more complex settings, such as lower ore grades, severe storms, and so on. Deeper deposits, tougher extent to which the specimen and high-stress settings are all factors to consider. The relevance of creation for the society is addressed in this section. Mining enterprise, as well as the programs that support it to perform. It also analyses the reasons and involved parties and current trends. The mining sector's digital transformation process is addressed, and several other pertinent developments that really are likely to shape the future of mining. A case study is included to show the technical and economic aspects of creating a design thinking initiative.
Keyword Mining innovation . Mining technology . Digital transformation . Industry 4.0

1Introduction

Over the beyond decades, the mining enterprise has needed to face a tough situation for its operation. Improving productiveness to triumph over herbal elements along with lowering ore grades, deeper deposits, and more difficult rock mass, mixed with an growing environmental and social awareness, has increase the enterprise to continuously paintings to beautify their techniques alongside the entire fee chain. In this, innovation performs a essential function with the aid of using supplying appropriate answers to surpass those difficulties, making sure the continuity and sustainability of the mining activity. There has been a ancient debate whether or not mining is certainly an modern enterprise or not. It is frequently perceived as a conservative quarter, in which innovation takes most effective a secondary function withinside the issues of companies. But on the identical time, many argue that mining is much more likely to be similar with high-tech industries, thinking about that it makes use of leading edge technology in its techniques, along with computerized or remote-managed machinery, and superior tracking structures for the gathering and evaluation of big quantities of data [1]. Nowadays, many applicable actors of the enterprise declare that mining goes via the primary levels of a deep changeover from the hand of virtual transformation. It is stated that this technique should extrade how mining is done, passing from human-run operations to self reliant or semi-self reliant remote-managed mines. Independent if absolutely computerized operations are performed withinside the close to destiny or not, the virtual transformation is already impacting the enterprise and could preserve doing so. This article ambitions to represent the innovation surroundings withinside the mining enterprise, specifically: & Importance of innovation for the mining enterprise: relation among exertions productiveness and innovation & Dynamics of innovation withinside the enterprise: drivers and actors & Current tendencies and destiny of the mining enterprise It will make contributions to enhance the knowledge of the dynamics and mechanisms worried withinside the innovation techniques, in conjunction with studying the contemporary fame and anticipated destiny of the mining enterprise, in phrases of technological advance. The scope of this paper covers the mining enterprise in standard and its whole fee chain (exploration, extraction, processing, and smelting and refining). However, with the aid of using the character of the topic, artisanal and small-scale mining were generally excluded from the evaluation, thinking about the ancient low diploma of technological specialization on this quarter. Also, for the instance and exemplification of sure factors made on this document, a unique awareness has been positioned withinside the big-scale copper mining quarter and the principle copper manufacturer countries.

2 Innovations in the Mining Industry

Cambridge Dictionary defines innovation as a brand new concept, method, design, or product, in addition to its improvement or use [2]. In widespread, innovation may be understood as a manner of change, via which a brand new concept or answer is carried out in a good, service, or efficient technique to create fee and meet new necessities from clients and better protection or environmental standards, amongst different goals. In this section, the significance of innovation for the mining enterprise is discussed. Firstly, the relation among innovation and hard work productiveness is examined. Then, a widespread view concerning the innovation dynamics inside the enterprise is provided, exploring the primary drivers and actors involved.

2.1 Innovation and Labor Productivity

A first technique to recognize the relevance of innovation in the enterprise may be made thru the evaluation of hard work productiveness. Technological advances typically have an effect at the output, permitting large manufacturing costs at the same time as keeping a comparable workforce, or without delay decreasing the wanted employees through the automation of processes. Nevertheless, modifications in hard work productiveness of a mine can be as a result of a sequence of different reasons. Natural factors, which includes lowering ore grade and deepening of deposits, suggest that a bigger quantity of fabric in extra complicated conditions should be eliminated to reap the identical very last steel output, consequently impacting negatively on hard work productiveness, at the same time as, in an aggregated view (e.g., whilst reading the mining enterprise of an particular country), the invention and exploitation of latest and higher deposits also can definitely effect the general hard work productiveness [3]. On the

alternative hand, in a high-charge mineral commodities scenario, groups are inclined to compromise their fees so that it will growth manufacturing.

2.2 Drivers for Innovation and Actors

As mentioned withinside the preceding section, innovation constitutes an essential aspect affecting the productiveness of mining operations. Examples of technology evolved to enhance the performance of processes, lessen costs, and in effect beautify productiveness are without difficulty found. Hydrometallurgical manufacturing technique SX-EW has been recognized as a first-rate Fig. 1 Labor productiveness for the Chilean copper enterprise, real and constrained (or adjusted) assuming no alternate withinside the area of mine output 1978–1997 (lots of copper contained in mine output in keeping with copper organisation employee). Modified after [7] Average exertions productiveness of Chilean mines for the length 1978– 2015, measured as lots of mine manufacturing in keeping with worker. Modified after [4] Labor productiveness of the mining region of decided on countries, for the length 1995–2013. Annual fee supplied as a percent of exertions productiveness in 1995 (100%). Modified after [4] Mining, Metallurgy & Exploration (2020) 37:1385–1399 1387 contributor for productiveness boom withinside the US copper enterprise over the past many years of the 20 th century [6]. Likewise, non-stop mining device in underground coal mining, together with draglines and bucket wheel excavators in floor coal mining, had been key advances to attain new ranges of productiveness in coal manufacturing. In smelting processes, the improvement of flash, and, extra recently, backside blowing furnaces, has had a extremely good effect in decreasing strength intake and OPEX

3 Current Trends and Mining of the Future

Defining a destiny view for an enterprise isn't a easy task. Nowadays, the arena is converting quicker than ever before. New technology are advanced each day, impacting the manner humans stay. The phrase “we stay in a exceptional international than the only in which our mother and father grew up” does now no longer absolutely cowl the fact of the beyond few decades. For example, in modern days, maximum humans could now no longer conceive their lives with out their smartphones, and despite the fact that the primary ones had been commercialized in 1992, the massification of those gadgets got here best a touch greater than a decade ago (e.g., the primary iPhone turned into advanced in 2007). Nevertheless, withinside the case of the mining enterprise, it's miles viable to become aware of sure tendencies that may be of assist to define this destiny scenario. First and maximum evident, it's miles the important technological shift happening throughout all industries: the so-known as Fourth Industrial Revolution, or certainly Industry 4.0, because the transition to the virtual era. Then, social and environmental issues are already compelling mining to search for safer, greater efficient, and sustainable approaches of undertaking the business. Reduction of electricity and water consumption, decrease emissions, and waste technology are all elements so one can be withinside the center of the “mine of the destiny.”

3.1 Digital Transformation in Mining

Over latest records and due to the fact the start of industrialization, numerous modifications in manufacturing paradigms have taken place, promoted through the surge and alertness of novel technologies. As proven in Fig 2., the arena has already visible 3 paradigm shifts, higher called business revolutions.

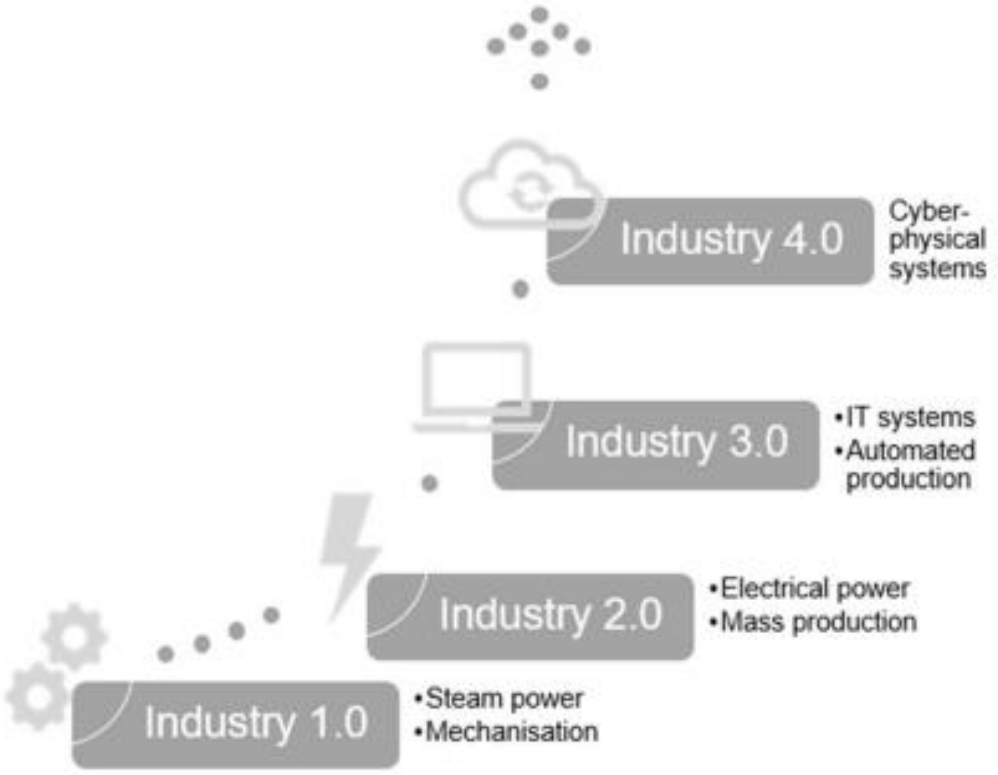

Fig.2 Industrial Revolutions

Currently, a brand new transformation is in development from the hand of cyber-bodily structures and a fixed of recent era developments, e.g., automation, net of things, and analytics [16, 17]. The Fourth Industrial Revolution brings a brand new idea of industry, additionally referred to as Industry 4.zero. This idea is primarily based totally on a sophisticated digitization of manufacturing strategies and the mixture of net-orientated technologies, permitting the relationship among clever sensors, machines, and IT structures throughout the cost chain. The implementation of those cyber-bodily structures ought to carry a chain of benefits, together with productiveness growth via way of means of the automation of manufacturing and decisionmaking strategies, discount of waste, development of device utilization, and upkeep fees discount. However, Industry 4.zero isn't always handiest approximately the adoption of recent technologies, however it'll additionally call for organizational modifications, specialised knowledge, and expertise [16, 17]. To acquire the state of affairs set via way of means of Industry 4.zero, organizations from all sectors, aleven though at extraordinary speeds, are enforcing the important modifications at a technological and organisation level. These modifications represent the procedure of virtual transformation.

3.1.1 What Is Digital Transformation?

Though the time period virtual transformation (DT) has been considerably utilized in current years, specifically to explain the variation method of companies to new virtual technology, there isn't a completely unique definition for it. On the contrary, there are many. Acknowledging this situation, and after an exhaustive evaluation of DT-associated literature, [18] gives the subsequent definition: ”a method that objectives to enhance an entity through triggering considerable adjustments to its residences thru combos of information, computing, communication, and connectivity technology.” The motive for the lifestyles of numerous acceptations for DT might also additionally lie withinside the variations amongst industries: every region operates particularly ways; therefore, every virtual generation could have a special impact, relying on the economic region adopting it. The particular information, computing, communication, and connectivity technology concerned in DT additionally range from one enterprise to another. In the case of mining, however, it's far feasible to discover a fixed of gear to be able to and are already affecting the tactics now no longer handiest on the mine web website online however throughout the operational and company gadgets inside a firm.

3.1.2 Key Technologies in the Digital Mine

DT is a transversal manner of alternate throughout the entire price chain of the mining industry, from the exploration to the manufacturing of very last products, their commercialization, or even the closure of operation sites. Experts, companies, and authorities companies had been discussing how the “virtual mine” need to appear to be at the same time as advancing ahead withinside the DT manner. how cutting-edge virtual technology are and could maintain affecting the one-of-a-kind regions of the business. As shown, novel technology are generating operational modifications throughout the price chain, and their use isn't always specific for a selected activity. For example, shrewd operation facilities are being applied for each extraction and processing operations. Likewise, augmented and digital reality, along side virtual twinning, are gear to be able to decorate the layout and creation of mining projects (“Establish” in Fig. 3, and the extraction and processing operations. While the view of the “virtual mine” may also range amongst corporations and organizations, it's miles feasible to outline a fixed of center technology that constitute the pillars of the DT withinside the mining industry [19–27]. These key factors are defined below.

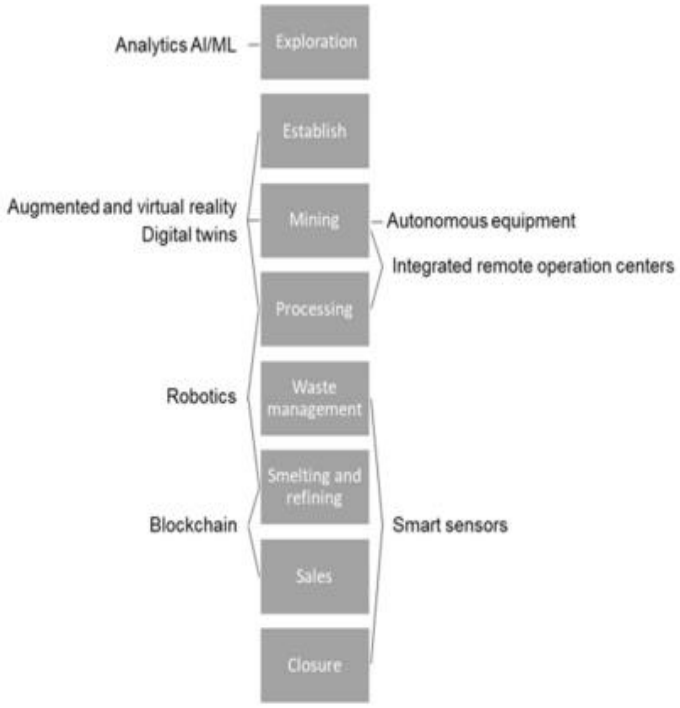

Fig. 3 DT technologies in the different stages of the mining value chain. Based on [19, 20]

3.1.2.1 Automation, Robotics, and Remote Operation

These technology would possibly keep the best degree of implementation many of the equipment provided via way of means of DT. The first and greater clean advantage of the automation of processes, use of robots in crucial activities, and far off operation centers (ROC) is the enhancing of safety, via way of means of lowering the quantity of operators required in unsafe sites [25]. ROCs also can extensively lessen OPEX and CAPEX of mining operations. Since much less paintings pressure is wanted on the mine site, fewer or none helping infrastructure is required, consisting of housing installations, hospitals, or schools. Also, different costs are reduced, consisting of transportation of operators. The effect on expenses is bigger because the region of the mine is greater far off, distant, and isolated [25]. The use of self sufficient system, consisting of hauling vans, LHDs, and drillers, is increasing rapidly. For example, international system producer Caterpillar has already furnished greater than 239 self sufficient vans for large-scale mining operations in Australia, Brazil, Canada, and the USA [28]. Similarly, Komatsu holds a complete fleet of 141 self sufficient vans disbursed in Australia, Canada, Chile, Japan, and the USA. In Chile, those automobiles perform in Codelco's mine Gabriela Mistral. Over the ten years of operation of the mine, the usage of self sufficient vans has allowed a widespread collision danger discount and excessive degrees of productiveness and tires performance [29]. By February 2020, a complete of 459 self sufficient haul vans had been accounted as energetic in mining operations across the world [30]. Though those system nevertheless constitute much less than 1% in comparison with the full of guide vans presently operating,1 they may be characterised as excessive 12 months-to-12 months growth: 32% withinside the 2019–2020 duration and better costs are predicted for the subsequent years, from the hand of widespread investments made via way of means of foremost groups consisting of BHP, Fortescue Metals Group, Rio Tinto, and Hancock Prospecting in Australia and Suncor Energy and Canadian Natural assets in Canada. In fashionable terms, except the blessings in safety, self sufficient system decorate productiveness and decrease operational expenses, via way of means of growing system's utilization (because of the non-stop operation), lowering variability withinside the manufacturing outcome, and enhancing tires and additives performances [20, 29].

3.1.2.2Internet of Things (IoT), Smart Sensors/Real-Time Data Capture

IoT is thought as a community of bodily objects, consisting of sensors, system, machinery, and different reassets of facts. The factors linked to this community can then interact, alternate records, and act in a coordinated way [31]. Thanks to advances in IoT technology, nowadays, it's far feasible to set up low-fee networks. Additionally, the improvement of clever sensors permits real-time seize of facts from machines and system throughout the operation. This technology of facts is the bottom to behavior an incorporated making plans and control, thinking about the extraordinary devices in the operation, and aid the decision-making process [20].

3.1.2.3 Analytics, Artificial Intelligence (AI)/Machine Learning (ML)

Due to the digitization of techniques, advances in IoT, and real-time facts seize, mining operations have large quantities of facts to be had concerning manufacturing, techniques, and overall performance of machines, amongst others. Through superior analytics strategies, it's far feasible to convert this records permitting its use for a higher making plans of sports and to aid rapid and powerful decision-making techniques for the operation. Predictive fashions also can be evolved to beautify upkeep of system, consequently enhancing productiveness [21]. AI/ML strategies also are being implemented for mineral prospecting [32–34]. It is anticipated that those strategies will optimize the prospection and exploration sports, decreasing fees and enhancing their accuracy.

3.1.2.4 Digital Twinning

The idea of virtual twinning refers to the development of a virtual version of the bodily operation. This is feasible the usage of the geological and engineering records of the site, however greater importantly, way to the real-time facts generated from the sensors linked throughout the operation. With the virtual dual of the mine, it's far feasible to carry out simulations and are expecting capability screw ups or downturns in system overall performance. Thus, the virtual dual constitutes a beneficial device to enhance operational making plans and decrease operational fees, via way of means of averting sudden interruption in manufacturing techniques and optimizing the upkeep of system [20, 21].

3.1.2.5 Current Status of DT

In its have a look at of 2017, the World Economic Forum and Accenture envisioned a capability advantage for the mining enterprise, attributable to DT, of US$ a hundred ninety billion over the duration 2016–2025, equal to about 9% of the enterprise's profit [26]. Correspondingly, withinside the USA, the mining enterprise has been covered a few of the organization of sectors with capability to boom productiveness from the similarly digitization of its assets, purchaser family members techniques, and variations in its workforce [35]. These expectancies are aligned with the consequences of a survey performed via way of means of Accenture in 2014

3.1.2.6 Challenges withinside the Implementation of DT

For the duration 2019-2020, the "virtual effectiveness" has been diagnosed as the second one maximum applicable hazard for the mining enterprise [41]. It highlights the significance of advancing in digitization, as a need for organizations to stay competitive. The fundamental hazard lies then at the reality that DT is frequently perceived as a venture one-of-a-kind of the records technology (IT) area.Nonetheless, to achieve a truly effective and valuecreative transformation, it must be carried out as a joint task across the organization, with a shared view of the business.

3.2 Mining beyond DT

In parallel with the technological wave added through the virtual transformation, a sequence of different tendencies had been gaining relevance withinside the mining enterprise over latest years. Driven through protection and environmental concerns, fee reduction, enhancement of efficiency, and productiveness withinside the operation, or a mixture of those motives, those tendencies are complementary to the technology 4.zero and provide an concept of the destiny paths that mining would possibly follow.

3.2.1 Electromobility

Electromobility, because the improvement and use of electricpowered vehicles, is a technological fashion throughout industries. From personal-use vehicles and public transportation vehicles, to heavy machinery, electromobility gives a cheap and greater environmentally pleasant opportunity to the usage of fossil fuels. Mining is mainly laid low with this paradigm change. Most cellular device in mining operations has been traditionally powered through inner combustion engines (ICEs), the use of diesel gas. While the effect of the bad components of those engines is probably bearable in open pit operations, in underground mines, wherein air flow can account for as much as 25– 40% of the entire strength costs, the state of affairs is different [43]. Diesel ICEs emit exhaust gases containing a sequence of pollution, along with unburned hydrocarbons (HC), carbon monoxide (CO), nitrogen oxides (NOx), and diesel particulate matter (DPM). Additionally, a big quantity of warmth is likewise produced. All those factors boom the call for for sparkling air waft so one can make sure a right running surroundings for operators and device, having a sizable effect on costs [44]. Moreover, because of the growing environmental and protection focus withinside the industry, rules concerning the admissible tiers of pollution have end up stricter withinside the beyond a long time and are possibly to end up even stricter withinside the future. At the identical time, after laborious shallow deposits, mining is shifting to deeper locations, annoying the temperature conditions [45]. Even aleven though a few strategies to offer electric powered strength had been used for a long term already (e.g., trolley assist), nowadays there are greater incentives to search for electric powered-powered options to update the cellular device which have been predominantly going for walks with diesel ICEs, like LHDs and haul trucks. According to the technique used to deliver the motor with electric powered strength, this device may be categorized into 5 categories [45]: & Trolley powered & Battery powered & Cable powered & Hybrid ICE/electric powered device & Hydrogen gas mobileular powered.

3.2.2 Invisible Zero-Waste Mining

The idea of a mining with out a effect at the floor isn't new. Underground operations had been the usage of their waste fabric to backfill open cavities left after ore extraction, specifically for balance motives and as a median to lessen haulage costs. At the identical time, this exercise reduces subsidence impact and, therefore, the effect at the floor above the underground mine. However, it isn't feasible to apply all of the waste extracted because of interference with the operation (e.g., for the duration of early improvement stages). Also, now no longer each mining technique permits backfilling application (e.g., caving operations). Therefore, it's far sure that effect at the floor may be considerably reduced, however maximum of the time it's far unavoidable. In this regard, in situ leaching (ISL), additionally known as in situ healing (ISR), constitutes an opportunity that minimizes the impact on floor and generates nearly 0 waste. This technique is known because the in-region leaching of the ore, healing of the enriched solutions, and their transportation to the floor for similarly processing.

3.2.3 Continuous Mining

Continuous extraction and fabric coping with structures were used for decades withinside the coal mining industry. In floor operations, this has been performed combining the movement of bucket wheels excavators for the extraction and conveyor belt structures for the shipping of coal and waste. Meanwhile, underground strategies inclusive of longwall mining and room and pillar (with the aid of using the use of non-stop miner gadget) have additionally presented non-stop flows of fabric. However, because of rock strength, maximum metal ore deposits do now no longer permit mechanical extraction strategies, making vital using drill and blasting, therefore, impeding non-stop operation. Traditional mining strategies combining drill and blasting, excavators for loading and cell gadget for hauling (or LHD for loading and hauling, in underground mining), have excessive ranges of operational inefficiency and coffee gadget utilization: great hauling cycles, wherein as a minimum 1/2 of of the time the cell gadget is empty, in conjunction with queues and ready instances at loading and dumping site, are a number of the inefficiencies of those processes.

4 Conclusions

Innovation performs an essential position withinside the mining enterprise as a device to enhance the performance of its processes, lessen costs, however additionally to fulfill the growing social and environmental issues amongst groups and authorities. Technological development has additionally been essential to permit the exploitation of recent deposits in greater complicated scenarios: decrease ore grades, intense climate conditions, deeper deposits, more difficult rock mass, and high-pressure environments. That is, the significance of innovation for the mining enterprise, as a vital thing withinside the development of exertions productiveness thru beyond decades, became analyzed. Though its relevance, mining corporations commonly display low tiers of R&D intensity, just like mature industries and some distance from high-tech sectors. The tendency to vertical disintegration has led companies to cognizance on their center business, depending especially on system producers and providers for the improvement of progressive solutions. Also, collaborative alliances among mining corporations, providers, and studies facilities percentage a widespread participation withinside the improvement of recent technologies.

References

1. Bartos PJ (2007) Is mining a high-tech industry? Resources Policy 32(4):149–158 2.
2. Cambridge Dictionary. INNOVATION | meaning in the Cambridge English Dictionary. (2010) .
3. Good deposits are not enough: mining labor productivity analysis in the copper industry in Chile and Peru 1992–2009. Resources Policy 35(4):247–256.
4. Fernandez V (2018) Copper mining in Chile and its regional employment linkages. Resources Polic.y
5. Tilton JE, Landsberg HH (1999) Innovation, productivity growth, and the survival of the US copper industry. Productivity in Natural Resource Industries:109–139.
6. Aydin H, Tilton JE (2000) Mineral endowment, labor productivity, and comparative advantage in mining. Resource and Energy Economics 22(4):281–293
7. Garcia P, Knights PF, Tilton JE (2001) Labor productivity and comparative advantage in mining: the copper industry in Chile. Resources Policy 27(2):97–105.
8. Upstill G, Hall P (2006) Innovation in the minerals industry: Australia in a global context. Resources Policy 31(3):137–145 .
9. Filippou D, King MG (2011) R&D prospects in the mining and metals industry. Resources Policy 36(3):276–284.
10. OECD (2017) OECD Science, Technology and Industry Scoreboard 2017: OECD.
11. Pietrobelli C, Marin A, Olivari J (2018) Innovation in mining value chains: new evidence from Latin America. Resources Policy 58:1– 10.
12. Stubrin L (2017) Innovation, learning and competence building in the mining industry. The case of knowledge intensive mining suppliers (KIMS) in Chile. Resources Policy 54:167–175.
13. Alta Ley. El Programa de Proveedores de Clase Mundial (PPCM). https://corporacionaltaley.cl/noticias/el-programa-de-proveedoresde-clase-mundial-ppcm/. Accessed 10 May 2019.
14. AUSTMINE (2015) New realities, bigger horizons. Australian Mining Equipment, Technology and Services (METS) National Survey .
15. COCHILCO (2019) Encuesta de Innovación en Empresas Proveedoras de la Gran Minería. Santiago, Chile.
16. Lasi H, Fettke P, Kemper H-G, Feld T, Hoffmann M (2014) Industry 4.0. Business & Information Systems Engineering 6(4): 239–242 .
17. Rüßmann M, Lorenz M, Gerbert P, Waldner M, Justus J, Engel P et al (2015) Industry 4.0: The future of productivity and growth in manufacturing industries. Boston Consulting Group 9(1):54–89.
18. Vial G (2019) Understanding digital transformation: a review and a research agenda. The Journal of Strategic Information Systems 28: 118–144.
19. Coombs D, O'Donnell C, Sparks J, Veiga P, Jones B (2019) Perspectives and opportunities in the mining equipment and services sector. Santiago, Chile .
20. Deloitte (2017) The digital mine. What does it mean for you? Kalgoorlie, Australia .
21. Bonomelli A (2018) Estrategia Digital Codelco. Santiago, Chile .
22. Canart G (2018) Mining in the Digital Era. Aachen, Germany .
23. Espinoza J (2018) Transformación Digital en Minería: la Clave de la Productividad Sustentable. Santiago, Chile.
24. Romano V (2018) Mining 4.0: maximizing the potential as a premium, predictable company. Aachen, Germany.
25. Sganzerla C, Seixas C, Conti A (2016) Disruptive innovation in digital mining. Procedia Engineering 138:64–71 .
26. World Economic Forum, Accenture. Digital Transformation Initiative: mining and Metals Industry; 2017.
27. Pino O (2018) Programa de Habilitación Tecnológica / Transformación Digital. Santiago, Chile 28. Mosqueira R (2019) Autonomía Open Pit. Santiago, Chile .
28. Canelo A (2018) 10 Años de Operación Autónoma en División Gabriela Mistral. Codelco. Presente y Futuro, Santiago, Chile .
29. GlobalData (2020) Development of autonomous trucks in the global mining sector.
30. Jeschke S, Brecher C, Meisen T, Özdemir D, Eschert T (2017) Industrial internet of things and cyber manufacturing systems. In: Industrial Internet of Things: Springer; 3–19.
31. Carranza EJM, Laborte AG (2015) Random forest predictive modeling of mineral prospectivity with small number of prospects and data with missing values in Abra (Philippines). Computers & Geosciences 74:60–70.
32. Chen Y, Wu W (2017) Mapping mineral prospectivity using an extreme learning machine regression. Ore Geology Reviews 80: 200–213.
33. Rodriguez-Galiano V, Sanchez-Castillo M, Chica-Olmo M, ChicaRivas M (2015) Machine learning predictive models for mineral prospectivity: an evaluation of neural networks, random forest, regression trees and support vector machines. Ore Geology Reviews 71:804–818.
34. Manyika J (2017) What's now and next in analytics, AI, and automation 36. Autonomous vehicles, electrification and automation with a focus on people. https://www.lkab.com/en/news-room/news/ sjalvkorande-fordon-elektrifiering-och-automation-medmanniskan-i-centrum/. Accessed 8 Jun 2020. .
35. International Mining. Resolute Mining starting to deliver automation benefits at Syama Underground - International Mining. https:// im-mining.com/2019/07/30/resolute-mining-starting-deliverautomation-benefits-syama-underground/. Accessed 8 Jun 2020. .
36. Resolute Mining. Syama - Project overview. https://www.rml.com. au/syama/. Accessed 8 Jun 2020.
37. Gustafson A (2011) Automation of load haul dump machines: Luleå tekniska universitet .
38. Parada S (2018) Innovación en Minería - EXPOMIN 2018. Santiago, Chile.
39. EY (2018) Los 10 principales riesgos de la industria minera 2019- 2020 .

40. Consejo de Competencias Mineras (2018) Impacto de las nuevas tecnologías en las competencias requeridas por la industria minera. Santiago, Chile.
41. Erdtmann B (2018) Productivity and safety enhancement with Siemens solutions for non-hazardous underground mines. Aachen, Germany
42. Varaschin J, de Souza E (2015) Economics of diesel fleet replacement by electric mining equipment. In: 15th North American Mine Ventilation Symposium.
43. Paraszczak J, Svedlund E, Fytas K, Laflamme M (2014) Electrification of loaders and trucks–a step towards more sustainable underground mining. In: Proceedings of the International Conference on Renewable Energies and Power Quality (ICREPQ'14). Cordoba, Spain; 7–10.
44. Valicek P, Fourie F (2014) Fuel cell technology in underground mining. In: The 6th International Platinum Conference,'Platinum– Metal for the Future', The SouthernAfrican Institute of Mining and Metallurgy; 325–332.
45. Epiroc. Zero emission Epiroc. https://www.epiroc.com/en-za/ innovation-and-technology/zero-emission. Accessed 8 Jun 2020.
46. Mining Technology. In charge: the battery technologies leading the way in mining. https://www.mining-technology.com/features/incharge-the-battery-technologies-leading-the-way-in-mining/. Accessed 8 Jun 2020.
47. International Mining. Sandvik's electric LHDs stepping up including new battery-assisted LH514BE model - International Mining. https://im-mining.com/2020/02/10/sandviks-electric-lhdsstepping-including-new-battery-assisted-lh514be-model/. Accessed 8 Jun 2020.
48. Seredkin M, Zabolotsky A, Jeffress G (2016) In situ recovery, an alternative to conventional methods of mining: exploration, resource estimation, environmental issues, project evaluation and economics. Ore Geology Reviews 79:500–514.
49. Sinclair L, Thompson J (2015) In situ leaching of copper: challenges and future prospects. Hydrometallurgy 157:306–324.
50. Schlueter R, Mischo H (2018) In-situ bioleaching in crystalline rockformations: comparison of conditioning methods for enhanced permeability. In: SME Annual Meeting.
51. Batterham RJ (2017) The mine of the future–even more sustainable. Minerals Engineering 107:2–7.
52. Scheepers E (2018) Vale's S11D Project. Aachen, Germany.
53. Orellana LF, Castro R, Hekmat A, Arancibia E (2017) Productivity of a continuous mining system for block caving mines. Rock Mechanics and Rock Engineering 50(3):657–663.
54. Codelco (2018) Memoria Anual 2018 .
55. Baraqui J (2014) Minería Continua: El Futuro de la Minería Subterránea. Santiago, Chile. 58. Codelco (2018) Investor Update October 2018. Santiago, Chile.
56. Carrasco F, Encina V, Le-Féaux R (2004) Continuous mining for caving method. In: Proceedings of MassMin 2004 Conference; 79– 82.
57. Orellana LF (2012) Evaluación de variables de diseño del sistema de minería continua a partir de experimentación en laboratorio. Master in Mining, Santiago.
58. Ramström M. Mining Industry Game Changer: Atlas Copco News. http://www.atlascopco.com.au/auus/news/companynews/amining-industry-game-change.aspx. Accessed 25 Dec 2016.