Contractor Companies' Small Projects Facing Mining 4.0 in Chile: How Risky Is the Implementation of Industry 4.0 for Them?

Camilo Peña Ramírez[1], Francisco Ríos Muñoz[2], Luis Espinoza Brito[1]*

Abstract
Despite the relevance of Chile's mining industry, risk models applied to contracts have not been intensively developed. This is a quantitative descriptive research, which focuses on the results of a risk assessment methodology applied for the analysis of potential industry 4.0 technologies to be implemented by contractor companies in Chile's mining sector.
In this paper, an overview about mining 4.0 was done and Chile's large mining companies were analyzed during 2021-2022, obtaining contracts information from a relevant copper producer. A case was selected to apply the model and semi-structured in-depth interviews were conducted with the stakeholders involved in this industry.
Based on our results we found small contracts concentrated the largest number of low and moderate- priority projects, but also the largest number of high-priority contracts. However, from a mining company's perspective, it seems that big projects are riskier than small projects under the future effects of Industry 4.0 technologies.

Keywords: Small projects; SME Supplier; Risk Management Methods; Mining 4.0, Contract Management

Submitted: September 6, 2023 / Approved: March 30, 2024

1. Introduction

The context in which this research is carried out is about an industry that begins its introduction into a new industrial revolution. In this way, and according to Kurzweil (2005) the world would reach a technological singularity in the next few decades, in which the pace of technological change will be so rapid, its impact so deep, that human life will be irreversibly transformed.

Mining industry diversity varies from manual to industrial operations. Thus, there are approximately 25,000 mining companies in the world today, including metals, industrial minerals, and coal (Hodge et al. 2022). This industry is also facing a technological shift with Industry 4.0 creating new conditions for mining (Lund et al, 2024), which is predominantly affecting industrial mining operations (Clausen et al, 2022).

Under this new revolution, mining companies in the world are developing and integrating Industry 4.0 technologies to improve efficiency, safety, and sustainability in their operations today. Some of the technologies being used include automation, robotics, artificial intelligence, 3D printing, augmented reality, Internet of Things (IoT), blockchain, and advanced analytics among others. In the case of Chile, mining companies and also providers are usually pioneers in the application of new technologies and they are one of the sectors with the most technology in this country[1], due to the use of satellite control, robotics, IT, and digital transformation among others. However, this has not necessarily been reinforced in the area of human capital (Meller, 2019) and these extractive companies usually show low levels of R&D intensity, similar to mature industries and far from high-tech sectors (Sánchez and Hartlieb, 2020).

Currently, copper is the main Chile's export product. In this context, it is known that the "red metal" is a very fundamental raw material for the manufacturing of all types of machinery and technological developments associated with electricity and electronics (Cochilco, 2017). Moreover, copper plays a strategic role in Chile's economy, the world's energy transition (Agnese . and Ríos, 2023) and to the transition to mining 4.0. In this context, the advent of Mining 4.0 could contribute to build a sustainable future for the mining industry (Jiskani et al., 2023).

The mining industry has historically been made up of companies with great purchasing power, which are obliged to maintain a high level of competitiveness (Vergara, 2012). In this context, and due to the large size of their facilities, the complexity of their extensive processes and technical difficulties, mining operations require a large amount of materials and supplies of all kinds to satisfy their productive needs (Tupa, Simota and Steiner, 2017; Tubis et al, 2020). Because of this, these companies have a wide portfolio of collaborators, suppliers and contractor companies that provide products, services and solutions to meet the demand of these requirements (Culver and Reinhart, 1989). In this way, it is important to mention that around 74% of supplier and contractor companies involved in Chile's mining industry are small businesses (Fundación Chile, 2019).

On the other hand, despite the relevance of the mining industry in Chile, risk models applied to contracts have not been intensively developed in the literature (Cardozo, Petter and de Albuquerque, 2022; Simensen and Perry, 1999). In this context, this is a quantitative

[1] For instance, Chile's mining suppliers have achieved the most extensive digital transformation, ranking 13 points above the national average for other industries (InvestChile-January,5,2023).

(1) Industrial Engineering and Organization Management Department, Playa Ancha University, Chile.
(2) Department of Economy and Business Organization Universitat Internacional de Catalunya, Spain.
*Corresponding author: friosmunoz@uic.es

ISSN: 0718-2724. (http://jotmi.org)

descriptive research, which focuses on the results of a risk assessment methodology applied for the analysis of potential industry 4.0 technologies to be implemented by contractor companies in Chile's mining sector.

The objective of this research is to assess which contracts and services are at imminent risk of change according to experts' forecasts because of industry 4.0 technologies integration. The target is to have better information for decision-making by a mining company's contract administration area.

We develop, a procedure by which a mining company or other industry may be able to study in a general way the technologies available in the market for its operations or contracts to be renewed or acquired. In this way, and through bidding processes, the collaborators or contractors offer their services with different technological options, so that finally the companies will able to choose the most appropriate, according to the degree of technological maturity, operational costs and initial investment for the service implementation.

In this paper, we ask: what happen with small, medium and large contractor companies in the middle of this technological revolution? what areas are the most critical? or what role play labor force in these matters? In particular, how risky are big and small projects? and how risky is for them the implementation of industry 4.0? In this way, we will try to offer a few intuitions on these pertinent questions to fill this gap in the literature and also trying to give some foundations to answer these questions.

We found mining 4.0 implementation poses risks to both large and small contractor companies. Nevertheless, it seems large and small contractor companies have different kind of risks when facing mining 4.0. In this regard, based on our results large contracts may be perceived as riskier than small contracts from a mining company's perspective due to higher financial investments, complexity, dependency on contractors, lack of skilled labor, and the role of labor unions. Smaller companies, such as Chile's small contractor companies, are also vulnerable due to limited resources and insolvencies, posing risks to their survival in the evolving mining industry.

The paper is organized as follows. We discuss the state of the art about industry 4.0 integration in the mining industry, in section 2. We also discuss our methodology and the risk analysis model for mining contracts applied to Industry 4.0 integration, in section 3. Our results are offered in section 4. We discuss our results in section 5. At last, section 6 concludes.

2. Conceptual Framework

2.1. Mining 4.0

Currently, the mining industry has a lot of challenges such as changes in the ore grade to be extracted, the increase in distances from mine to mineral processing plants, climatic conditions or high-risk levels to which their workers are exposed (Elguind et al., 2011). These are some of the many reasons why this pioneering industry in many areas is also a pioneer in the development and integration of new technologies[2] into its core productive processes (Okada, 2022; Van Hau et al, 2022; Pałaka et al., 2020; Zhironkina and Zhironkin, 2023; Efimov & Efimova, 2021; Sam-Aggrey, 2020).

In this context, there is a need to invest in new technologies and seek to remain competitive in the global market by the use of them. Today, a technological revolution is taking place in the mining industry, with the incorporation of artificial intelligence, big data, and digital interconnection of devices to various industries, a phenomenon also called Industry 4.0.

Currently, it is known that digital capabilities positively influence firm performance through technological capabilities (Heredia et al, 2022) and because of this mining companies in the world are integrating Industry 4.0 technologies to improve efficiency, safety, and sustainability in their operations (World Economic Forum, 2017). In this way, a brief overview about Industry 4.0 in the mining industry is summarized in Table N°1a and N°2.

In the case of Chile's copper mining industry, previous studies such one published by Consejo Minero (2018) had shown the maximum technological level identified in mining and processing [3]. However, some industry 4.0 technologies are beginning to use include automation, robotic technology, 3D printing, artificial intelligence, Internet of Things (IoT), machine learning, advanced analytics and blockchain among others. In this context, as illustrated in Table N° Ic (See Annexes), automation is being used for tasks such as drilling, blasting, and hauling, reducing the need for manual labor and increasing productivity. In addition, IoT sensors are being used to monitor equipment performance and prevent breakdowns, reducing downtime and maintenance costs (Hirman, et al, 2019). Artificial intelligence is being used to analyze large amounts of data and optimize processes, improving efficiency and reducing waste.

Nevertheless, in spite of mining companies are taking advantage of Industry 4.0 technologies to increase their competitiveness and sustainability in the global market, it remains increasingly difficult for mining companies in the world to decide which digital technologies are most relevant to their needs and individual mines (Barnewold and Lottermoser, 2020; Ediriweera and Wiewiora, 2021).

[2] Moreover, in the short and medium term, the technology developed by extractive companies for remotely controlled terrestrial operations provides a suitable "ecosystem" for the development of space tech start-ups and new technologies for mining in space (Ríos Muñoz et al. 2024).
[3] The results of this analysis are detailed in the Table N° Ia and N° Ib (See Annexes).

ISSN: 0718-2724. (http://jotmi.org)

Table N° 1. Uses and applications of industry 4.0 technologies in world's mining (Source: Own elaboration).

Technology	Uses	Reference
Autonomous Haulage Systems (AHS)	They use advanced technologies like GPS, radar, and LiDAR sensors to operate 24/7, allowing efficient transportation of materials.	Gaber et al. (2021); Abdellah et al. (2022)
Drones and Unmanned Aerial Vehicles (UAVs)	They are used for surveying, mapping, and monitoring mining sites.	Nguyen et al. (2023)
Artificial Intelligence (AI)	It is used for resource exploration, mine planning, and mineral processing optimization.	Noriega and Pourrahimian (2022)
Advanced sensors and monitoring systems	They monitor various aspects of mining operations, providing real-time insights. IoT technologies connect mining ecosystem components, enabling real-time monitoring and predictive maintenance.	Zang et al. (2022)
Big data analytics	It is used to optimize extraction methods, reduce environmental impact, and improve resource management.	Fekete (2015)
Virtual and augmented reality	They are used for training and simulation.	Tkachuk et al. (2023)
Blockchain technology[4]	It is being explored to improve transparency and traceability in the mining supply chain, smart contract among others uses.	Jha et al. (2023)
Digital twinning	It creates digital replicas or simulations of physical assets, allowing for real-world testing and optimization.	El Bazi et al. (2023)
3D printing	It is also being adopted for various applications, including prototyping, product development, and construction.	Feng and Carvelli (2022)

Table N°2. Main findings about Industry 4.0 in the world's mining industry (Source: Own elaboration).

Reference	Industry	Country	Objective	Main Findings
World Economic Forum (2017)	Metals	Global	How digital technologies are transforming the mining and metals industry.	It develops a detailed analysis to assess the impact of different digital initiatives within the sector and quantifies the value they could create for the industry and society over the next decade.
Center for Copper and Mining Studies (2018)	Copper	Chile	It identifies solutions and innovations of the industry 4.0 to mining	Some stages of the mining process such as processing and service have begun the implementation of new technologies, but not before ensuring an adequate level of maturity of them.
Consejo Minero (2018)	Copper	Chile	It develops a survey about the state of the art on technologies in mining and supplier companies.	There are 77 technologies associated with the Fourth Industrial Revolution, related with artificial intelligence, robotics or the Internet of Things, among others.
Bertayeva et al. (2019)	Metals	Russia	It highlights the global implementation of Industry 4.0 in various sectors, including coal, and highlights Russia's positive experience with Smart Mine and Smart Cut projects	It identifies trends in innovative mining development and systematizes the basic elements of the Industry 4.0 project on mining processes, allowing for the development of a technological platform for future projects.
Center for Copper and Mining Studies (2020)	Copper	Chile	It estimates the state of the art for technologies used by Chile's large copper companies and the technological potential that the different mining processes would acquire by the use of them.	The probability of implementation for technologies associated with Industry 4.0 in the Chilean mining industry was determined, which is summarized in the Table Nº Ic (See annexes).
Consejo Minero (2020)	Copper	Chile	It develops a Roadmap, which seeks to enable a portfolio of projects and activities in the short, medium and long term that aims at the development of the industry 4.0 in Chile's mining.	A roadmap.
Barnewold and Lottermoser, (2020)	Metals		It provides an overview of digital technologies currently relevant to mining companies.	Results demonstrated that currently 107 different digital technologies are pursued in the mining sector, also revealing a limited uptake of digital technologies in general and that the uptake increases with the run-of-mine production.

[4] Since 2020 a blockchain initiative has been running in Chile to support distributed generation transactions and carbon markets in general, as mining companies are currently under increasing pressure to reduce their carbon emissions (World Bank, 2020). In addition, there are a lot of supplier companies developing different blockchain applications for mining (Fundación Chile, 2019).

Kagan et al. (2021)	Metals	Russia	It discusses about the possible directions of Russian mining companies' transformation under the influence of Industry 4.0.	The level of production automation and administrative processes is low, and the use of digital technologies is still limited mainly to pilot projects in most Russian mining companies. This shows a certain conservatism in Russian companies and the lag in the implementation of digital platforms, despite the interest of companies' management in using digital technologies.
Ulewicz et al. (2022)	Metals-	International	It aims to assess the feasibility of implementing the assumptions of Industrial Revolution 4.0 in the mining industry.	It identifies nine stakeholder groups and defines technical criteria for scenario assessment. The research focuses on digital competencies deficit, generational change, and the new worker-miner-operator 4.0 competency requirements.
Skenderas, and Politi (2023).	Metals	-	It aims to identify gaps, barriers, inefficiencies, and enablers in the regulatory framework of the mining sector to facilitate the utilization of new technologies.	It highlights the risks and barriers of incorporating new technological innovations into the mining sector, highlighting the need for structured cybersecurity regulations and addressing the impact on local societies. It suggests that a comprehensive regulatory framework, involving governmental authorities, companies, and educational institutions, is necessary to ensure the sector's sustainability and viability.
Zhironkina and Zhironkin (2023).	Metals	International	It provides a comprehensive overview of the transformation of mining industries due to Industry 4.0 technologies, highlighting the opportunities and threats of replacing physical systems with cyber-physical ones.	The mining sector needs to expand inflow of funds and innovations to ensure sustainable supply of mineral raw materials, prevent fuel and energy crises, and minimize environmental impact. Mining 4.0, combines digital and convergent technologies to ensure stable development, environmental safety, and profitability.

On the other hand, the growth and export capacity of the supplier sector of Chile's mining industry has been constant in recent decades (Prochile, 2022). This has also contributed to the development of countries like Chile. In this way, the supplier sector's constant work for the creation, development and implementation of new technologies has generated new or better products and services to take competitive advantages in the mining market (Phibrand, 2021).

Currently, these companies have recognized the potential benefits of Industry 4.0 technologies and they are investing in their development and implementation. As seen in Table N° Ia and N° Ib (see annexes), many world-class contractor mining companies are developing and integrating industry 4.0 technologies to improve their operations and stay competitive in the mining market[5]. In this context, contractor mining companies usually develop technologies to improve the supply chain, process optimization, safety and environmental sustainability. This can include IoT sensors to monitor environmental impacts, or digital tools to help workers identify hazards and stay safe on the job among other innovations (Muniz et al, 2023).

In some cases, these companies are partner with technology companies or research institutions like AMTC[6] to develop and implement new technologies.[7]

It should be noted that contractors in the mining industry are often responsible for specific tasks or projects, such as drilling, excavation, transportation, maintenance, service or construction projects and by using industry 4.0 technologies, they can improve these tasks and streamline their workflows. In this way, the use of machine learning applications as a predictive approach to forecast the most likely cost and schedule overruns in projects have been tested in the oil and gas industry (Natarajan, 2022). In addition, and considering that it is imperative to have real-time information for optimum decision-making in modern mining, Industry 4.0 technologies are the mechanisms for integrating business systems, manufacturing systems and processes (Sishi and Telukdarie, 2020).

But, what happens with small and medium contractor companies in the middle of this technological revolution? It should be noted Industry

[5] Chile's mining companies have also been participating actively in the Open Innovation Platform for Mining, led by Fundación Chile (Bhp billiton, 2016). Open innovation is a strategy where firms combine knowledge from both internal and external sources, leveraging their own knowledge and exploring the knowledge of their environment. This strategy is relevant for small-and medium-sized enterprises (Carrasco-Carvajal et al., 2023).
[6] The Advanced Mining Technology Center (AMTC) is the leading research center in Chile in Technology Applied to Mining and whose mission is to generate world-class multidisciplinary research, and transfer new technologies and advanced human form responding to the challenges of mining to ensure the welfare and development of Chile and the world.
[7] Companies are more likely to adopt new 4.0 technologies when they have suppliers of technological services, universities, and research centers validating and developing the latest technologies for local and sectoral conditions (Geldes, 2023).

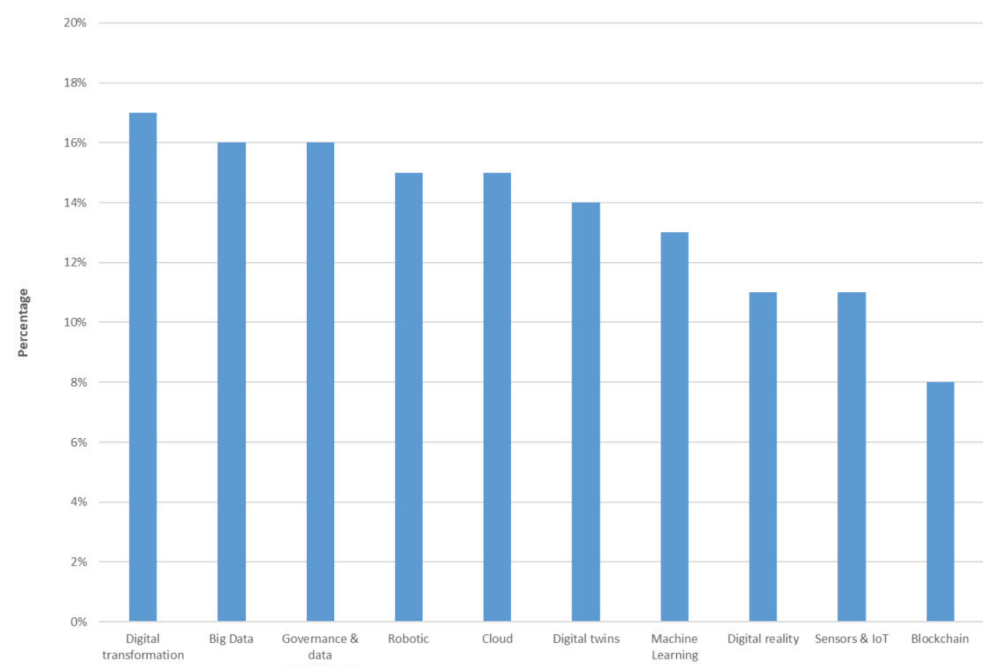
4.0 implies many changes and risks to face by mining companies, and in this transition it seems there is a forgotten link such as employees, SME contractors and service providers (Birkel et al, 2019).

By one hand, it is known new technologies are expected to significantly impact mining workers including operators, maintainers, supervisors, and professionals (Consejo Minero and Fundación Chile, 2023). On the other hand, contractor and provider companies are a fundamental part for the industry development. Nevertheless, under this revolution towards mining 4.0, they could also be strongly affected by this new stage of changes (Rylnikova et al. 2017; Saldana et al. 2019). For example, technologies like robotic, AI or machine learning could increase unemployment or blockchain could also disrupt contracts management in the future[8].

Nevertheless, as can be seen in the Figure N°1, some supplier and contractor companies in Chile are also recognizing the potential benefits of industry 4.0 technologies and investing in their development and implementation. In this context, some of these companies' projects have been awarded[9] and recognized as "*successful cases of supplier innovation in mining*" by the market [10].

Under this view, it is possible to find a percentage of these companies developing solutions based in digital transformation (17%), government and data management (16%) and big data (16%), being blockchain the lowest percentage (8%). Particularly, it is interesting to note suppliers, which have contracts in the open pit mine, have the most development of this technology (See Table N° Id in annexes). Likewise, a segment that more addresses trends in blockchain is administrative services (Fundación Chile, 2019). On the other hand, Table N°3 shows the average of supplier & contractor companies developing trends in technology mining.

Figure N°1 Supplier & contractor companies which claim to be developing trends in technology mining (Fundación Chile, 2019).



[8] Among the most promising uses of blockchain are those related to business activities that can be easily decentralized (Kunhahamed, P.K. and Rajak, S., 2023; Agnese, 2021; Schwab, 2016). In addition, and considering information is also becoming a deliverable, digital information is changing how projects are delivered enabling greater sharing, remote access, searching, and updating of information with visibility across supply chains and with owners, operators, and end users. Whyte (2019).
[9] See Avonni awards in the category Mining and Metallurgy.
[10] See Fundación Chile, 2022, 2021, 2018, 2017, 2016.

Table N°3. Average of supplier & contractor companies developing trends in technology mining (Fundación Chile, 2019).

Area	**Average%**
Open pit mining	23.1
Concentration	20.6
Hydrometallurgy	20
Undergroung mining	18.7
Tailing	17.5
Tranversal	15.8
Mining planning	14.9
Smelting	11.8
Refining	10.2
Commercialization	8.9
Geology & Exploration	8.4
New copper applications	3.9

2.2. Mining Contracts and Risk Analysis

Mining companies usually subcontract supplier companies for a few reasons. By one hand, subcontracting can provide a way to reduce costs, improve efficiency also reducing the possibility of strikes by labor unions among others (Rupprecht, 2014). In addition, subcontracting can allow mining companies to tap into specialized expertise or equipment without needing to invest in these resources themselves (Vidal Véjar, 2021). It allows mining companies to focus on their core business activities, such as exploring and developing mineral resources, while leaving the operational and support tasks to experienced subcontractors. This can help mining companies to operate more efficiently and achieve higher productivity. Additionally, subcontracting can provide mining companies with greater flexibility to adapt to changing market conditions more quickly and effectively.

According to a survey published by Fundación Chile (2019), around 74% of supplier and contractor companies involved in Chile's mining industry were small businesses (see Table N°4). In this context, a mining company usually has between 700 and 1,600 active contracts executing in parallel. Under this perspective, a study by Cochilco (2022) indicates that more than 275 thousand people worked in mining in the year 2021 and 76% of them were contractors.

Table N°4. Characterization of suppliers of services, equipment and technologies in Chile's mining industry (Fundación Chile, 2019).

Company Size	Average Sales (USD)	Staffing (workers)	Percentage
Small Business	3,600,000	1-50	74%
Medium-sized companies	10,000,000	51- 199	17%
Large companies	28,000,000	200 and more	9%
Total	-	-	**100%**

On the other hand, digital transformation (DT) is also a significant risk for the mining industry, with businesses facing challenges in innovation and strategic focus due to various barriers. In this regard, the majority of digital transformation initiatives fail before they are completed and problem does not just affect the mining industry. In this way, Abdellah et al. (2022) investigate the major challenges encountered in digital transformation projects and to propose a strategic solution for implementing and scaling digital initiatives. In addition industry 4.0 integration in the mining industry has risk. In this way, Gaber et al.(2021) explore the connection between autonomous haulage systems (AHS) safety in mining environments and cybersecurity and communication, highlighting challenges and open issues. It concludes that addressing cybersecurity can enhance operations safety and ensure reliable communication.

Currently, as illustrated in the Table N°5, there are several challenges that contractors may face when implementing Industry 4.0 technologies in Chile's mining industry. Some of them include cost, data privacy and security, workforce resistance, labor force, complex integration with existing systems and regulatory challenges among others.

ISSN: 0718-2724. (http://jotmi.org)

Table N°5. Contractors' challenges in Chile's mining industry that may face when implementing Industry 4.0 technologies (Source: Own elaboration according to expert opinions).

Challenge	Description
Cost	The initial investment required for implementing Industry 4.0 technologies can be high. Contractors may need to invest in new hardware and software systems, as well as hire and train new employees with the necessary skill.
Data privacy and security	As Industry 4.0 technologies rely heavily on data collection, contractors must ensure that they comply with data privacy laws and implement robust security measures to protect sensitive information.
Workforce resistance	Some employees may be resistant to learning new technologies and processes, which could impact the successful implementation of Industry 4.0 initiatives.
Labor force	Industry 4.0 technologies are expected to impact human capital, prompting companies to adapt through upskilling, reskilling, and hiring.
Integration with existing systems	Integrating Industry 4.0 technologies with existing systems can be challenging, especially if those systems were not designed to work together.
Regulatory challenges	Contractors must also comply with regulations imposed by regulatory agencies, which can vary by region. Compliance with these regulations may require modifications to Industry 4.0 solutions.

Referring to how mining contracts are managed today, there are a series of factors that must be considered for carrying out a correct administration of contracts, such as standardized operating plan analysis by the mining company, which then is contrasted with the main shortcomings and non-compliance that plan faces (Torres, 2015). However, despite the relevance of the mining industry in Chile, risk models applied to contracts have not been intensively developed in the literature.

In this context, Peña -Ramírez et al., (2022) developed a risk analysis model for mining contracts (see Appendix 10), which consists of a risk analysis methodology for current contracts, and also a tool for the analysis of possible technologies to be implemented by contractors (Cooper, MacDonald and & Chapman, 1985). In practical terms, this model allows mining companies at any level (corporate, by country, by site, etc.) to carry out an analysis of contract risks, anticipating administrative times and the feasibility of implementing new contracts and technologies 4.0. The method will also avoid awarding on the fly, supplier and technology dependence, including other series of actions that can occur during contract management.

3. Methodology

A qualitative research at descriptive level has been done. It seeks to test a risk analysis model for mining contracts in the scenario of a future Industry 4.0 integration in this sector. The sequence of work is described as follows (Peña-Ramírez et al, 2022).

In this research, a new instrument or method to obtaining information and analysis is developed, so that contract administrators and managers of the mining industry can identify the risk of new technologies and the administrative management of related contracts.

In this way, three large mining corporations in Chile were analyzed by a survey during the year 2021, obtaining through formal channels primary information about contracts of each company. After that, a case to validate the model was defined using as criteria the number and amounts (MMUS $) of contracts and the data quality that described each contract.

In addition, semi-structured in-depth interviews were conducted with industry experts, such as contract administrators from external suppliers and providers, contract managers from mining companies and department managers. This made it possible to validate the criteria and categories of analysis established in the theoretical framework. A company with more than 700 current contracts was chosen for applying the consequence / probability matrix. This was adjusted to the staff criteria, who designs it to achieve a pre-selection that determines which of all contracts should be considered as a priority to carry out a risk analysis in the face of a technological change. In this way, among the selection criteria considered were contract amount, staffing, contract duration and renewal date. Peña-Ramírez et al (2022) create a methodology for the development of a contract pre-selection table and a contract criticality matrix. Working with 3 companies and using mining companies contract information from transparencia portal, mining companies contract information from corporate digital portals, unspecialized entities and gathering information of mining contract from professionals and experts, they determined one of the companies with base information: staffing, the contract duration, the cost of the contract, process or service area and the remaining time for contract expiration. With Feedback and opinions from professionals and experts in the industry, and gathering information of mining contracts from professionals and experts they pre-selected contracts and they created a contract criticality matrix.

On the other hand, a second instrument was designed. This was a simplified template in which, before the bidding date, the different proponents, suppliers and collaborators had to mention the current or mature technologies that were being used by them or the contract for their services development. Additionally, collaborators had to propose which ones were the new technologies that were coming into force for the service development, also indicating a cost estimation for implementing them, the main benefits that these would grant to the service and for which its offer would stand out with respect to their competitors.

Finally, a template was designed to be developed by the supplier's contract manager or mining company' specialist. This was used to evaluate qualitatively and quantitatively which of the current and projected technologies were a good option to consider in the future, estimating also the risk level of these proposals. Peña-Ramírez et al (2022) create a methodology development of forms and templates for the study of new technological implementations to contract. They start by reviewing risk management methods, continue with feedback and opinions from professionals and experts in the industry, and then select ISO 31,000 and ISO 31,010 to carry out the selection of risk management tools with an analysis of business impact and scenario analysis. Finally, they design templates for technologies implementation of contractor/mining company (For details see Appendix 10).

It should be noted that both instruments were validated in expert interviews.

3.1. Contract pre-selection matrix or selection criteria table

For this survey carried out, all mining companies had between 700 and 1,600 contracts. It should be noted that the average of suppliers in mining companies is around 30% of total active contracts to date. This is because of a supplier or collaborating company usually has between 2 and 4 active contracts with the mining company.

Given these high amounts of contracts to be evaluated, a contract preselection matrix was carried out for giving a priority level of some contracts over others during the review process. On one hand, it was done to avoid a disorder and an agglomeration of tasks or contracts to be evaluated. On the other hand, it also was done to make better use of the company's resources and standardize the criteria by homogenizing the system. This was achieved by organizing contracts according to the risk level obtained by them in the matrix result, which allowed them to be prequalified according to a criteria assigned to their characteristics by the professional in charge of contract administration.
For the design of this type of matrix, there were no limits on the scale for possible numerical values to assign to the qualities or process points. In this way, it is usually concluded that the highest results of the matrix are those with the highest risk and they are the first to be analyzed. In this case, a 3x3 matrix was considered, being the criteria remaining time of the contract versus impact risk, with 3 levels for each criterion, according to Table N ° 6.

After identifying and indicating which was the main objective of this matrix, which problem it sought to solve with it, the variables that would be used as pre-selection criteria for the development of this matrix were chosen and studied.

In this case, various variables of contracts were determined, considering quantitative values such as their economic cost or duration and expiration times. After that, qualitative characteristics such as the area where the service contract was supported and the problems that this could generate the mining company in case of failures were also considered.

In addition, the risk that a technology change could mean for the service was also added. This required a detailed analysis of possible cost increases, or losses this could imply for mining companies' competitiveness due to non-acquisition of technologies with a high level of potential profit for the mining industry.

These values were classified from 1 to 10 according to their importance level, among them were;

- The staffing: Number of people who are part of the contract.
- The contract duration: Number of years each contract lasts.
- The cost of the contract: The expenditure of money that must be made during the contract duration.
- Process or service area: According to the probability of technological change for the contract area, and its possible contribution to the productive chain.
- The remaining time for contract expiration: The period of time until the service expiration.

Once the variables had been determined, a classification was made to each item according to the criteria established by the mining company and / or an expert in contract management. For this case, maintaining mostly the mining companies' criteria, a higher numerical value was fixed for the following items: staffing, contract duration, service area, contract costs and expiration time. Subsequently, the following equation was proposed to determine the criticality level of the contract:

Criticality level of the contract = (Staffing criteria + Contract duration criteria + Service area criteria + Cost criteria) * (Expiration time criteria)

In this research, the values indicated in the following table were assigned, which were also distributed proportionally, according to the number of contracts that meet each criterion, with the following possible results.

Once the result of the base criteria has been obtained, the evaluated contracts were projected in the matrix that indicates their criticality level (See Table N°6). Finally, and by the use of this method, it is possible to determine in a simplified way, which contracts have priority over others.

Table N° 6. Contract criticality risk matrix. Source (Self made).

Impact → / Time ↓	Low Risk Impact	Medium Risk Impact	High Risk Impact
Low Remaining Time	60 - 89 Moderate Priority	90 - 119 High Priority	120 - 230 Urgent Priority
Medium Remaining Time	23 - 59 Low Priority	60 - 89 Moderate Priority	90 a-119 High Priority
High Remaining Time	1 - 23 Very Low Priority	23 - 59 Low Priority	60 - 89 Moderate Priority

3.2. Case Study

The organization of the mining company's contracts in the case study was carried out by two teams. On one hand, there is a contracts & supplies management, which is mainly focused on processes contract related to the company. On the other side, there is a projects management, which is mainly focused on the administration and validation of new contracts related to company's projects and construction area. It should be noted that the criteria for the contract bidder evaluation in the mining industry are the service cost and the technical capabilities offered in proposals. These criteria receive a different valuation level and application according to the company. In some mining companies technical evaluations of proposals are carried out first, and later, whoever exceeds the established minimum can apply for the economic evaluation. However, in the case study, the evaluation of both criteria is carried out in parallel, being able to adjust the values in the development of this evaluation.

In the same way, the pre-selection of the contracts to be evaluated depends on different criteria. For this work, the criteria proposed below (Table N°7) were taken into consideration during the development of the contract selection matrix.

Table N° 7. Criteria applied to the risk matrix case study. (Peña -Ramírez et al., 2022)

Variable	Quantity/range	Score
Staffing	1 a20	1
	21 a 60	2
	61 a 120	3
	121 a 360	4
	Over 361	5
Contract Duration	1 year	1
	2 years	2
	3 years	3
	4 years	4
	More than 5 years	5
Area (According to the Probability of Technological Change for the Contract Area.	Geology and Extraction	2
	Projects and Construction	2
	General Management	3
	Mineral Transport	3
	Maintenance Services	3
	Processing	4
	Process Management	5
Contract Cost	Between USD 1 and 999k	1
	Between USD 1M and 1,999M	2
	Between USD 2M and 2,999M	4
	Between USD 3M and 3,999M	6
	More than USD 4M.	8
Multiplicative Factor for Expiration Time Criteria	Between 1,621 and 99,999 remaining days	2
	Between 541 and 1,620 remaining days	4
	Between 181 and 540 remaining days	6
	Between 61 and 180 remaining days	8
	Between 1 and 60 remaining days	10

4. Results

4.1. Sample Characterization

The contracts data were collected from an important mining company in Chile. The sample considered 770 contracts with a staffing of more than 25 thousand people, which were valued at 1,264 MM USD for their execution. As illustrated in Table N°8, contracts had an average of 33 people, a budget of 1.6 MM USD and a duration of 3.7 years. In this way, the sample included short and long-term contracts. In this context, some of them started in the year 2017 and the duration fluctuated between 261 and 1,979 days. The Figures A1, A2 and A3 show the normal distribution curves for staffing, contracts cost and duration (See annexes). It should be noted that processing, projects & construction and general management had the largest number of active contracts, staffing and cost (See Table N°9).

On the other hand, it is interesting to note that there were low correlations between these three variables in the sample and we found a high data dispersion in contracts belonging to the same area (see Table N° Ie in annexes). In this way, and given the particular nature of each contract, trends were not found not even in contracts executed in the same productive area (See Figures N°A4, A5 and A6 in annexes).

Table N° 8. Summary of Contracts Statistics.

Parameter	Staffing	Contract Cost (USD)	Duration (Days)
Max	1,247	12,000,000	1,979
Min	1	500,000	261
Median	6	1,000,000	1,459
Average	33	1,642,208	1,345
Standard Deviation (SD)	104	1,305,554	424

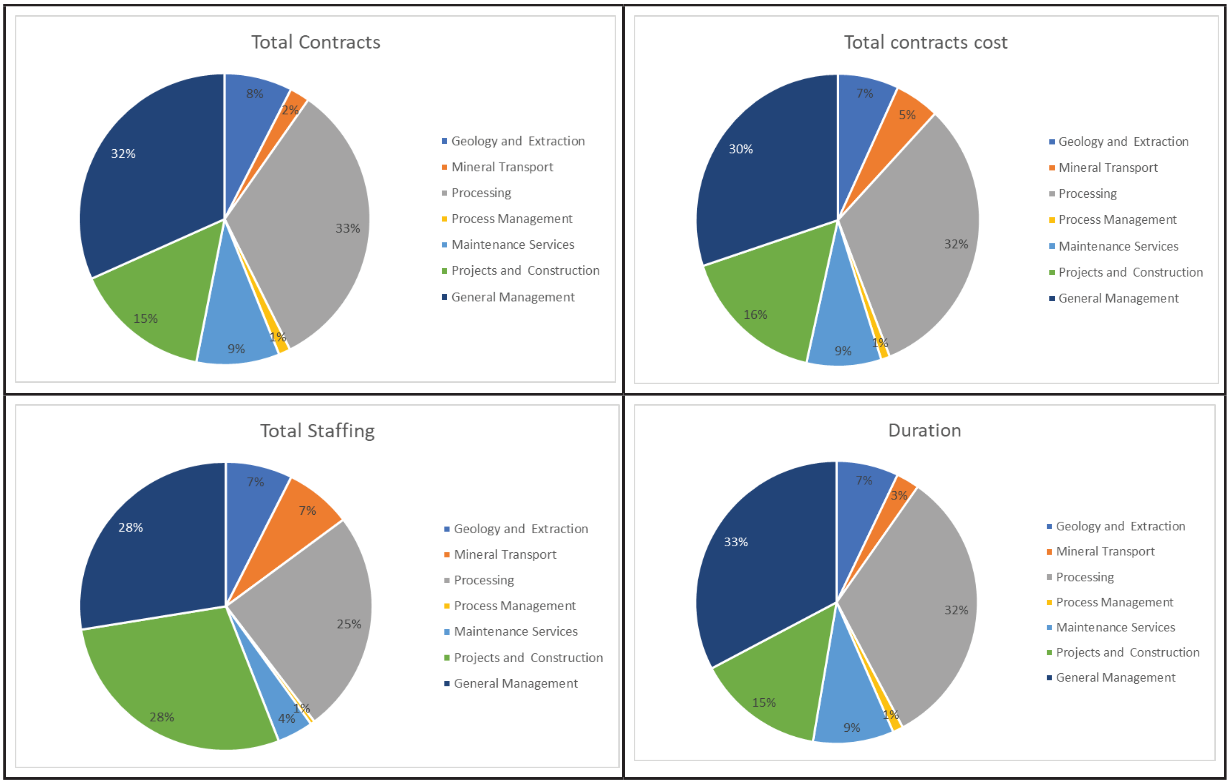
Table N° 9. Summary of active contracts classified according to area.

Area	Total Contracts	Total Staffing	Total Contract Cost (USD)	Total Duration (Days)
Geology and Extraction	58	1,897	87,900,000	73,672
Mineral Transport	17	1,908	64,000,000	27,429
Processing	253	6,416	405,100,000	336,520
Process Management	10	118	12,700,000	12,321
Maintenance Services	71	1,023	107,600,000	95,815
Projects and Construction	117	7,285	207,200,000	151,060
General Management	244	7,104	380,000,000	339,048
Total	770	25,751	1,264,500,000	1,035,865

Referring to the relevance of productive areas, it is important to mention more than 80% of contracts in this sample were from processing, general management and construction projects areas (See Figure N°2)

ISSN: 0718-2724. (http://jotmi.org)

Figure N°2. Relevance of different areas.



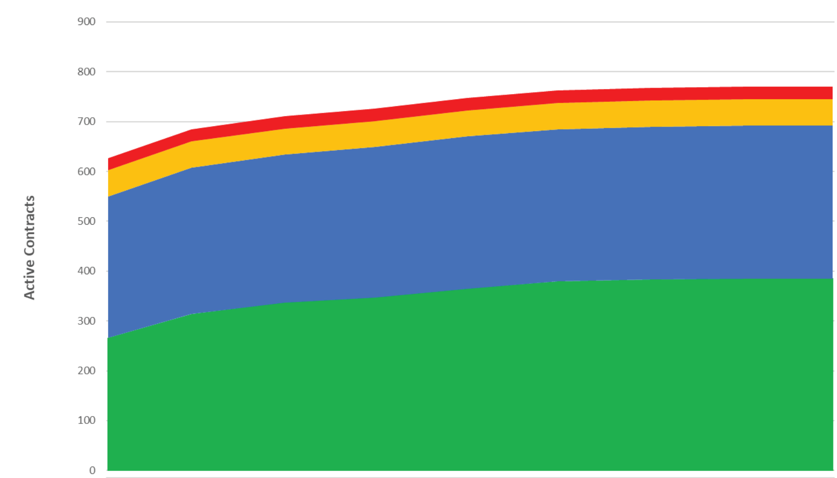
4.2. Data Modeling

4.2.1. Evolution of Mining Company's Contracts Portfolio

After applying the model to database was possible to observe the monthly risk evolution of mining company's contracts classified according to their criticality level during 9 months. It is interesting to note that the number of all active contracts was increasing because of new projects, which continuously started since January 2021. Thus, the mining company reached a peak of 770 active contracts at the end of September.

In this context, as can be seen in Figure N°3, 25 contracts were classified as urgent priority with a potential high-risk impact in the criticality matrix at the end of September 2021. The rest of contracts had a high (53), moderate (307) and low level of criticality (385) in the matrix.

Figure N°3. Monthly evolution of mining company's contracts classified by criticality level (Total Contracts: 770).



	31-01-2021	28-02-2021	31-03-2021	30-04-2021	31-05-2021	30-06-2021	31-07-2021	31-08-2021	30-09-2021
Urgent Priority	25	25	25	25	25	25	25	25	25
HighPriority	52	52	52	52	52	53	53	53	53
Moderate Priority	284	294	297	302	305	306	307	307	307
Low Priority	266	314	337	347	365	379	383	385	385
Very Low Priority	0	0	0	0	0	0	0	0	0

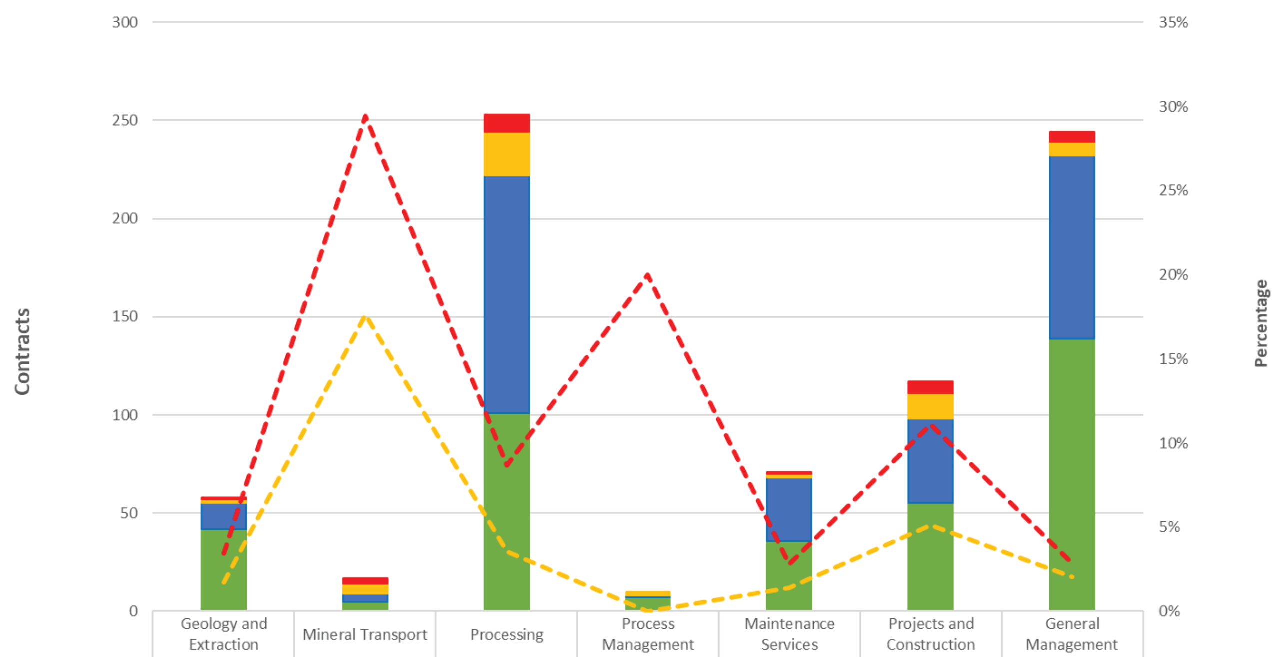
4.2.2. Evolution of Mining Company's Contracts Portfolio by Productive Area

From a Monthly evolution of mining company's contracts by area classified according to their criticality level data, and as we expected, all active contracts were increasing because of new projects in all productive areas. Furthermore, some increases where associated to a contracts transference from one category to another.

4.2.3. Contracts' Criticality Level by Productive Area

Referring to the contracts' criticality level of each productive area the Figure N° 4 shows the model results at the end of September 2021. In this context, for this case study it is possible to observe processing and general management had the largest number of low and moderate-priority contracts. In addition, these areas had also the largest number of high and urgent-priority contracts with projects and construction area. Nevertheless, and referring to the proportion of urgent and priority contracts, it is interesting to note that mineral transport and process management had the largest percentage of high priority contracts. Likewise, mineral transport only had a significant relevance in the category of urgent priority. Similar analysis can be done in other areas using the model data.

Figure N°4. Results for all contracts classified by area and criticality level (Updated September, 2021).



	Geology and Extraction	Mineral Transport	Processing	Process Management	Maintenance Services	Projects and Construction	General Management
Urgent Priority	1	3	9	0	1	6	5
HighPriority	2	5	22	2	2	13	7
Moderate Priority	13	4	121	1	32	43	93
Low Priority	42	5	101	7	36	55	139
% Urgent Priority	2%	18%	4%	0%	1%	5%	2%
% HighPriority	3%	29%	9%	20%	3%	11%	3%

Area

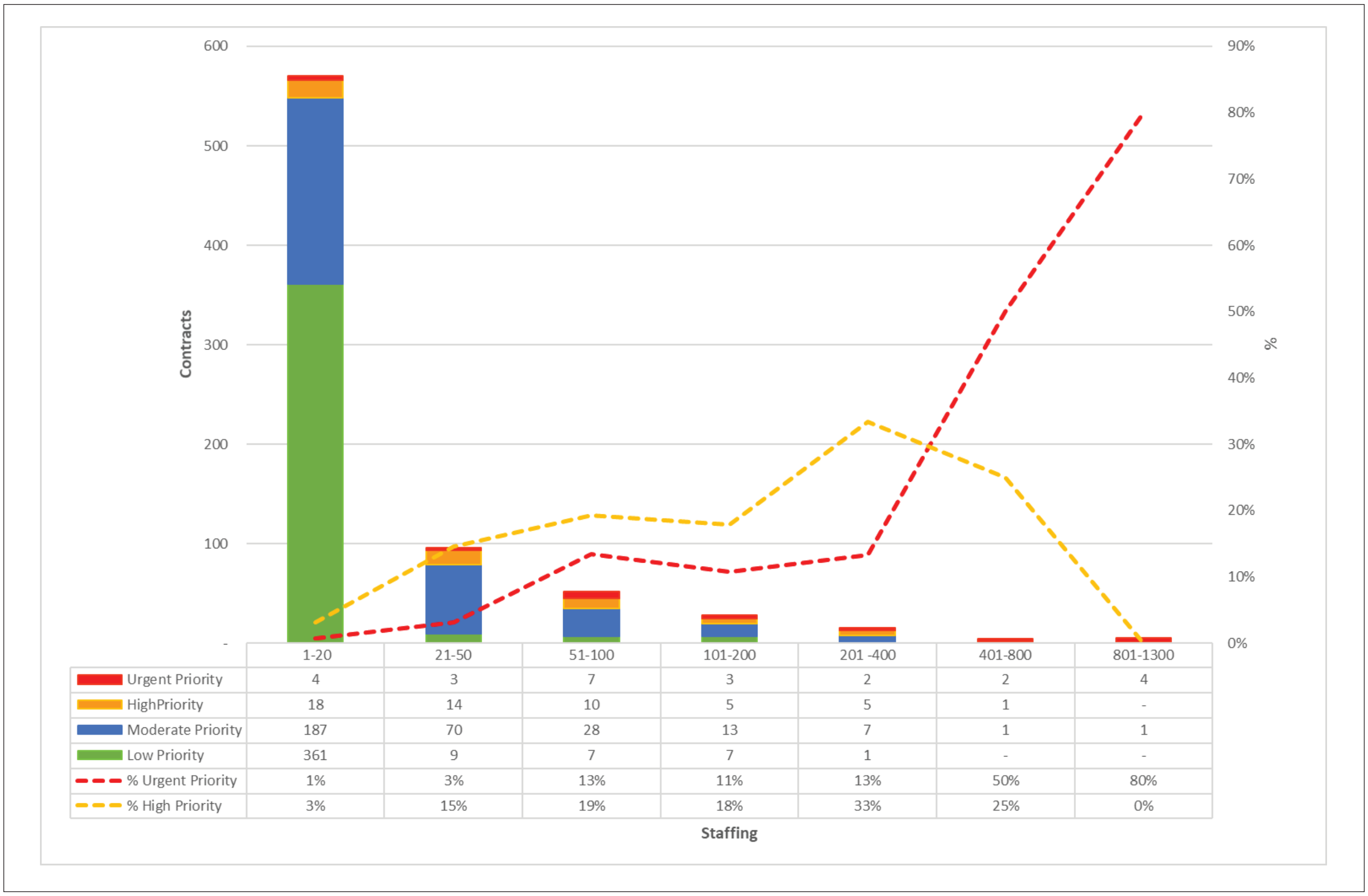
4.2.4. Contracts' Criticality Level by Company Size: Labor force and Cost

With respect to the contracts' criticality level classified according to number of people (staffing) the Figure N° 5 shows the model results at the end of September 2021. In this context, for this case study it is possible to observe that small contracts (below 50 people) concentrated the largest number of low and moderate-priority projects, but also the largest number of high-priority contracts. In addition, there were no significant differences between them for urgent-priority contracts. However, it is interesting to note that large contracts had a big proportion of urgent-priority projects and they would seem to be riskier than small projects under the future effects of industry 4.0 technologies.

A similar analysis can be done for urgent priority contracts in previous months using the model data.

ISSN: 0718-2724. (http://jotmi.org)

Figure N°5. Results for all contracts classified by the number of people and criticality level (Updated September 2021).



	1-20	21-50	51-100	101-200	201 -400	401-800	801-1300
Urgent Priority	4	3	7	3	2	2	4
HighPriority	18	14	10	5	5	1	-
Moderate Priority	187	70	28	13	7	1	1
Low Priority	361	9	7	7	1	-	-
% Urgent Priority	1%	3%	13%	11%	13%	50%	80%
% High Priority	3%	15%	19%	18%	33%	25%	0%

Finally, the result for all contracts classified by their cost and criticality level was also obtained at the end of September 2021. In this context, for this case study we found that intermediate contracts (between 500,000 -3,500,000 USD) had the largest number of low and moderate-priority contracts.

In addition, in the case of bigger contracts there were no significant differences between them for urgent-priority contracts. However, as we expected, large contracts (over 3,500,000 USD) had a big proportion of urgent-priority projects and they would seem to be riskier than small projects under the future effects of Industry 4.0 technologies.

A similar analysis can be done for urgent priority contracts in previous months using the model data.

4.2.5. Evolution of High and Urgent-Priority Contracts

Particularly, we are interested in the monthly evolution of high and urgent-priority contracts. In this context, and referring to high-priority contracts, as we expected the number of these contracts showed no significant increase over the time (see Figure N°3). This can also be observed when analyzing the data of monthly evolution of high priority and urgent priority contracts classified by productive area. Therefore, processing and projects & construction areas had a significant relevance also had the largest contribution on criticality level over the past time period. In addition, for this case study is also possible to observe these contracts showed no increase over the time.

Finally, the data of monthly evolution of % high-priority and urgent-priority contracts classified by productive area also highlights about the progress of these contracts over the time. As we expected, mineral transport and process management had the largest percentage of high-priority contracts. Mineral transport only had a significant relevance in the case of urgent priority contracts and these contracts also showed no significant increase over the time.

5. Discussion

5.1.-Risk of contracts by Productive Areas

Our case study reveals that processing has the highest number of low and moderate-priority contracts, along with high and urgent-priority contracts. Moreover, mineral transport has the highest percentage of high priority contracts.

In this regard, if we analyze supplier and contractor companies, which claim to be developing trends technology in mining we will find our results make sense. For instance, around 20% of suppliers (see Table N°3) were developing industry 4.0 technologies for concentration and hydrometallurgy processes by 2019 (Fundación Chile, 2019), which means mineral processing is a focus for providers. Therefore, as seen in Table N°Ib (see annexes), this makes sense considering the most important providers and contractor companies have implemented automation technologies on mineral processing main equipment in Chile (Consejo Minero, 2018).

However, despite 23.1% of suppliers were involved in open pit mining 4.0 (see Table N°3), it seems the use of technologies like autonomous haulage systems (AHS) has not fully been implemented in this mining company, which accounts the highest percentage of high priority contracts in mineral transport. It is known that autonomous haulage systems in surface mines eliminates human factors, increasing safety, productivity, and cost reduction. However, it seems this technology is not spreading as quickly as expected in the world due to development issues (Voronov et al.,2020).

On the other hand, even though 8.4% of geology contractors were developing mining 4.0 our results show this area was one of the lowest risk areas. This is probably because of the fact that exploration and drilling equipment are mostly teleoperated by a human expert in Chile (see Table N°Ia in annexes). Moreover, the use of drones for mapping and exploration is a mature technology today and mining and contractor companies only face the challenge of creating a uniform group of pilots for drone flight and maintenance tasks (Minería Chilena, 2021).

5.2. The role of labor force in contractor companies

According to Consejo Minero and Fundación Chile (2023), new technologies related to industry 4.0 are expected to significantly impact mining and contractor companies and their employees including operators, maintainers, supervisors, and professionals 11. In this context, these technological advancements will impact human capital through changes in functions and profiles, particularly in the areas of extraction, processing, and maintenance. Considering the most affected profiles are likely to be those of operators and maintainers, the mining and contractor companies' main actions for adapting human capital include upskilling, reskilling, and hiring.

However, due to the fact that technological changes would be produced within five years, human capital seems to became an important risk factor for industry 4.0 integration. Under this view, this factor would become relevant in large contracts. This is in line with our results, which suggest that big contracts had a big proportion of urgent-priority projects and they would seem to be riskier than small projects under the future effects of industry 4.0 technologies.

In this regard, Lund et al. (2024) explores the growing need for skilled labor in the mining industry, highlighting the aging workforce and the need for new technologies. While research exists on labor requirements, there is limited knowledge on how to utilize existing mining workforce skills[12].

5.3. Risks of large contracts due industry 4.0 integration

According to our results, the industry 4.0 implementation in the mining industry's large contracts may also be perceived as riskier compared to small contracts. This could be due to several reasons such as:

- *Higher financial investment:* Big contracts typically involve higher financial investments compared to small contracts. This means that the stakes are higher, and any potential failures or delays in the implementation could result in significant financial losses for the contractor and also mining company.
- *Complexity of implementation*: Implementing Industry 4.0 technologies in the mining industry can be complex and challenging. Big contracts usually involve more complex solutions and require more resources and expertise to implement successfully. This increases the risk of encountering technical difficulties or delays in the implementation process.
- *Dependency on the contractor:* Big contracts often involve outsourcing the implementation of Industry 4.0 technologies to external providers. This dependency on the provider may introduce additional risks related to the contractor's capabilities, reliability, and alignment with the company's objectives.
- *Impact on the overall operation*: The successful implementation of Industry 4.0 technologies can significantly impact the efficiency and productivity of a mining operation. Big contracts have the potential to disrupt the entire mining operation if not executed successfully, leading to potential production downtime and loss of revenue.
- *Lack of skilled labor force*: Considering 29% of labor force is more than 45 years old (Consejo Minero and Fundación Chile, 2023) it seems the level of skill and expertise in industry 4.0 technologies within the labor force of mining contractor companies is a challenge that can become a complex risk factor in large contracts.
- *Labor union cooperation:* It is noted that mining 4.0 will decrease traditional labor requirements, generating unemployment in several economic sectors in the world including the mining industry (Chukwuere, 2024; Alper et al., 2023; Castillo-Vergara, 2023; Kuzior, 2022; Koropet &Tukhtarov, 2021; Szabó-Szentgróti et al, 2021; Stojanova et al, 2019; Uğurlu & Pajo, 2019; Kurt, 2019; Görmüş, 2019; Flynn et al, 2017). In this way, it is necessary a transparent workforce management and close trade union cooperation (Lööw et al, 2019) because large contracts' potential strikes are also a risk factor[13]. In this way, workers will contribute to industry 4.0 integration when the company supports job enrichment, qualification, upskilling and salary (Muniz et al 2023).

[11] The study involved 16 mining companies representing 95% of the national copper production, one lithium producer and 11 suppliers of the main value chain in Chile.
[12] Currently, around 6% of contractor's labor force involved in Chile's mining industry is 18-24 years old and 29% is seasoned miners (Consejo Minero; Fundación Chile, 2023). Young population is familiar with industry 4.0 technologies (Cotet el al, 2020) and they will fully work using them in the future mining. Neverthelss, despite technological optimism positively influences perceived usefulness and ease of use of Industry 4.0 technologies by young trainee (Castillo-Vergara et al., 2022), it will be important to utilize older miners' knowledge for technology development and knowledge transfer to newer miners (Lund et al., 2024).
[13] Currently subcontracted workers in Chile's mining industry has become an important social movement (Leiva and Campos, 2013; Hughes, 2016; Pérez, 2022). In this context, labor union leaders have received training in mining 4.0 today, covering topics like value chain, climate change, circular economy, automation, digitalization, and female industry participation (Consejo Minero; Fundachión Chile, 2023).

On the other hand, regarding labor-intensive construction subcontractors, Thomas and Tang (2010) suggest critical success factors (CSFs) include managerial performance, financial performance, and labor-intensive specific factors, which is also in line with Cesário and Noronha (2009). In the case of equipment-intensive subcontractors Thomas et al. (2009) identified seventeen CSFs, mostly internal, grouped into six major components: market position, equipment-related factors, human resources, earnings, managerial ability to adapt to changes, and project success-related factors. In this context, and considering our findings, it makes sense that big projects are riskier than small ones under the future effects of Industry 4.0 technologies.

Under this view, while big contracts offer the potential for greater rewards, they also come with higher risks compared to small contracts in the mining sector's industry 4.0 implementation. Due this, we believe companies should carefully assess these risks and develop mitigation strategies to ensure successful implementation.

5.4. Risks of small contracts due industry 4.0 integration

However, SMEs are also vulnerable under industry 4.0 integration. In this way, industry 4.0 implementation in SMEs faces challenges such as lack of experience, limited resources, lack of methods, government policies, among others (Castillo-Vergara, 2023). For instance, due to limited resources Australian's SME companies has been rocked by waves of insolvencies in recent times (Smith and Sepasgozar, 2022) and Chile hasn´t been the exception. In this context, according to Sicep (2023), when analyzing the number of Chile's contractor companies involved in the mining sector in the period 2021-2023, it shows a contraction of 8.4% in the total number of supplier companies, decreasing from 3,333 in the year 2021 to 3,053 in the year 2023. When carrying out the analysis by company size, the small companies mainly explains Chile's trend, which is associated with the post-pandemic effects. In this context, small companies experienced a 22.4% contraction, while medium-sized companies a 4.3% increase, and large companies an 8.6% increase. Under this perspective, small companies are hardly in a position to integrate industry 4.0 into their operational contracts generating for them other kind of risk related to their survival in the context of the evolution toward mining 4.0. For that reason, SMEs integration into Industry 4.0 requires institutional policies, local entrepreneurship, technology adoption, collaboration, financing, and organizational capacity development, requiring collaboration between companies and universities (Geldes et al, 2023).

5.5. How risky is for large and small contractor companies the implementation of industry 4.0?

It seems large and small contractor companies have different kind of risks when facing mining 4.0. By one hand, industry 4.0 implementation in the mining industry's large contracts may be perceived as riskier than small contracts from a mining company's perspective due to higher financial investments, complexity of implementation, dependency on contractors, impact on overall operation, lack of skilled labor force, and relation with labor union. In this way, big contracts can disrupt entire mining operations, leading to potential production downtime and revenue loss. Additionally, mining 4.0 will decrease traditional labor requirements, necessitating transparent workforce management and close trade union cooperation.

On the other hand, SMEs are also vulnerable under industry 4.0 integration, as they have been hit by waves of insolvencies due to limited resources. In this regard, Chile's small contractor companies have experienced a contraction in recent years. Under this view, many small bussines are unable to integrate industry 4.0 into their operational contracts, generating risks related to their survival in the context of the evolution toward mining 4.0.

6. Conclusions

Currently, mining companies are integrating Industry 4.0 technologies to improve efficiency, safety, and sustainability in their operations. Some of the technologies being used include robotic, automation, artificial intelligence, machine learning, augmented reality, 3D printing, Internet of Things (IoT), blockchain, and advanced analytics among others.

In this context, mining companies are taking advantage of Industry 4.0 technologies to increase their competitiveness and sustainability in the global market.

The research paper has addressed a niche and underexplored area by focusing on the impact of Industry 4.0, specifically on small and medium-sized contractor companies within Chile's mining sector. This particular lens provides the research with a degree of novelty as it zeroes in on a subset of enterprises that may face unique challenges and risks related to adapting Industry 4.0 technologies.

The integration of industry insights and the creation of a conceptual framework specifically for the mining industry regarding Industry 4.0 constitutes an original approach. Granting a deeper insight into the practical implications for that sector.

On the other hand, mining companies usually subcontract supplier companies to reduce costs, improve efficiency and productivity, also reducing the possibility of strikes by labor unions. It allows mining companies to focus on their core business activities, while leaving the operational and support tasks to experienced subcontractors. In this context, around 74% of supplier and contractor companies involved in Chile's mining industry are small businesses.

Under this perspective, there are several challenges that contractors in Chile's mining industry may face when implementing Industry 4.0 technologies.

It should be noted that many supplier and contractor mining companies are also developing industry 4.0 technologies to improve their operations, streamline their workflows and stay competitive. Thus, contractor mining companies are recognizing the potential benefits of industry 4.0 technologies and investing in their development and implementation.

Nevertheless, the implementation of Industry 4.0 in the Chilean mining industry could present significant risks for contractor companies. By one hand, there could be significant financial investments required to implement new technology, which would impact their bottom line. Additionally, there may be a learning curve associated with using new technology, which could require training and resources. Another risk associated with Industry 4.0 is the potential loss of jobs for manual laborers as automation and advanced technology are implemented in the industry. This could lead to workforce restructuring and potential backlash from labor unions. Finally, there may be regulatory and legal barriers that need to be overcome when implementing new technology, which could lead to delays and additional costs for contractors.

Despite these challenges and risks, Industry 4.0 can offer significant benefits to contractors in the mining industry in Chile, such as increased efficiency, productivity, and safety. By working with experienced Industry 4.0 solution providers, contractors can manage the risks and successfully implement these technologies.

On the other hand, currently risk models applied to mining contracts have not been intensively developed in the literature. The cases found were each company's internal procedures to different stages of projects life cycle, but not specifically to contracts. Although there are a lot of studies and surveys about the industry technological changes, there are no instruments and models available before this research to analyze the risk of mining contracts in Chile.

Based on our results after applying the model to the selected company chosen as a case study, we found small contracts concentrated the largest number of low and moderate-priority projects, but also the largest number of high-priority contracts. However, from a mining company's perspective, it seems to be that big projects are riskier than small projects under the future effects of Industry 4.0 technologies. In this regard, Industry 4.0 implementation in large contracts of Chile's mining industry could be riskier due to higher financial investments, complexity, dependency on contractors, lack of skilled labor and relation with labor unions. Thus, big contracts can disrupt operations, leading to production downtime and revenue loss. SMEs, involved in Chile's mining sector are vulnerable to insolvencies due to limited resources, posing risks to their survival in the mining 4.0 evolution.

The proposed method would allow any analyst, project manager or professional involved in mining companies contract areas to evaluate the risk of Industry 4.0 integration in mining contracts, which could also be used in other heavy industries like steel, chemistry, oil and gas. In practical terms, our model would allow heavy industries at any level (corporate, by country, by site, etc.) to carry out an analysis of contract risks, anticipating administrative times and the feasibility of implementing new contracts. In addition, the method would also avoid awarding on the fly, supplier and technology dependence, including other series of actions that can occur during contract management.
The discussion on the benefits of Industry 4.0 might examine associated risks. To develop a comprehensive view, future research can present industry-specific challenges, such as cybersecurity concerns, the need for workforce retraining, or the implications of technological obsolescence.

Finally, considering the large number of contractor employees working in Chile's mining, the application of similar analytical methods is an option to assess the impact that smart contract associated to blockchain technology could have in the mining industry in the next future.

7. Author declarations

- **Funding Information:** Not applicable.
- **Conflict of Interest:** On behalf of all authors, the corresponding author states that there is no conflict of interest.
- **Ethics approval/declarations:** All of the material is owned by the authors and/or no permissions are required.
- **Consent to participate:** Not applicable.
- **Consent for publication:** All authors consent to publish this article and no additional permissions are required.
- **Data Availability:** Data subject to third party restrictions. The data of mining companies´s contracts that were used to develop the model of this study are confidential and restrictions apply to the availability of them, and so are not publicly available. Data are however available from the authors upon reasonable request.
- **Code availability:** Not applicable.

8. References

Abdellah, W., Kim, J., Hassan, M., & Ali, M. (2022). The key challenges towards the effective implementation of digital transformation in the mining industry. Geosystem Engineering, 25 (1). DOI: 10.1080/12269328.2022.2120093

Alper, A. E., Alper, F. Ö., & Ozayturk, G. (2023). Dynamics of Technological Unemployment, Leadership, and Entrepreneurship during the Industry 4.0 Revolution. In *Agile Leadership for Industry 4.0* (pp. 21-46). Apple Academic Press.

Alves Cantini, F., Otávio Petter., C., & Rodrigues de Albuquerque, N. (2022). Monte Carlo simulation risk analysis for underground mining projects Tecnol Metal Mater Min. 2022;19:e2681 | https://doi.org/10.4322/2176-1523.20222681

Agnese, P. (2021). On Blockchains, Cryptos, and Media of Exchange. Not there (yet). Int. J. Intellectual Property Management, 11(1), 81-94.

Agnese, P., & Rios, F. (2023). Spillover Effects of Energy Transition Metals in Chile. IZA Institute of Labor Economics. Discussion Paper Series, 1-34.

Barnewold, L., & Lottermoser, B. (2020). Identification of digital technologies and digitalisation trends in the mining industry. International Journal of Mining Science and Technology, 747-757.

Bertayeva, K., Panaedova, G., Natocheeva, N., Kulagovskaya T., & Belyanchikova T. (2019). Industry 4.0 in the mining industry: global trends and innovative development. E3S Web of Conferences 135, 04026 ITESE-2019

Bhp billiton (2016). Sustainability Report BHP Chile. Minera Escondida and Pampa Norte. https://www.bhp.com/-/media/documents/media/reports-and-presentations/2017/170807_bhpsustainabiltiyreportbhpchile2016.pdf

Birkel, H. S., Veile, J. W., Müller, J. M., Hartmann, E., & Voigt, K. I. (2019). Development of a risk framework for Industry 4.0 in the context of sustainability for established manufacturers. Sustainability, 11(2), 384.

Cardozo, F. A. C., Petter, C. O., & de Albuquerque, N. R. (2022). Monte Carlo simulation risk analysis for underground mining projects. Tecnologia em Metalurgia, Materiais e Mineração, 19, 0-0.

Carrasco-Carvajal, O., Castillo-Vergara, M. & García-Pérez-de-Lema, D. (2023). Measuring open innovation inSMEs: an overview of current research. Review of Managerial Sciences (17), 397–442.https://doi.org/10.1007/s11846-022-00533-9

Castillo-Vergara, M., Álvarez-Marín, A., Villavicencio-Pinto, E., Valdez-Juárez, L.E. (2022). Technological Acceptance of Industry 4.0 by Students from Rural Areas. Electronics 2022, 11, 2109. https://doi.org/10.3390/electronics11142109

Castillo-Vergara, M. (2023). Industria 4.0 en la Pyme: Management & Technology. J. Technol. Manag. Innov. (18): 2, 3-4.

Castillo-Vergara, M., & Araneda, M. (2023). Impacto de la tecnología de la industria 4.0 en Jóvenes. Observatorio Económico, (175), 2–4. https://doi.org/10.11565/oe.vi175.493

Center for Copper and Mining Studies. (2018). Impact of new technologies on the skills required by the mining industry. Santiago: Mining Skills Council.

Centro de Estudios del Cobre y la Minería. (202). Hacia una minería 4.0: Recomendaciones para impulsar una industria nacional inteligente. Santiago: CESCO.

Cesário, M., & Noronha, T. D. (2009). Factors affecting the adoption of new technologies by labour-intensive firms: an empirical exercise on European southern regions. Estudos III, 215-237.

Chukwuere, J. E. (2024). Conceptualizing predictive conceptual model for unemployment rates in the implementation of Industry 4.0: Exploring machine learning techniques. arXiv preprint arXiv:2403.13536.

Clausen, E., Sörensen, A., Nienhaus, K. (2022). Mining 4.0. In: Frenz, W. (eds) Handbook Industry 4.0. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-64448-5_40

Cochilco. (2017). Tendencias de Usos y Demanda de Productos de Cobre. Santiago: Cochilco.

Cochilco. (2022). Yearbook: Copper and other mineral statistics 2002-2021. Santiago: Cochilco.

Consejo Minero; Fundación Chile. (2023). El Estudio de Fuerza Laboral de la Gran Minería Chilena 2023-2032. Santiago: Consejo Minero y Fundachión Chile.

Consejo Minero. (2018). Impacto de las Nuevas Tecnologías en las Competencias Requeridas por la Industria Minera. Santiago: Consejo Minero.

Consejo Minero. (2020). El Roadmap: Digitalización para una Minería 4.0. Santiago: Consejo Minero.

Cooper, D. F., MacDonald, D. H., & Chapman, C. B. (1985). Risk analysis of a construction cost estimate. International journal of project management, 3(3), 141-149.

Cotet, G., Carutasu, N., & Chiscop, F. (2020). Industry 4.0 Diagnosis from an iMillennial. Educational Perspective. Education Sciences. 10(1):21. https://doi.org/10.3390/educsci10010021

Culver, W. W., & Reinhart, C. J. (1989). Capitalist Dreams: Chile's Response to Nineteenth-Century World Copper Competition. . Comparative Studies in Society and History, 722-744.

Domingues, M.S., Baptista, A., Diogo, M.T. (2017). Engineering complex systems applied to risk management in the mining industry. Int. J. Min. Sci. Technol., 27, 611–616.

Ediriweera, A., & Wiewiora, A. (2021). Barriers and enablers of technology adoption in the mining industry. Resources Policy, 73, 102188.

Efimov, V.I., Efimova, N.V. (2021). Digital Transformation of Open-Pit Coal Mining in Russia. In: Zavyalova, E.B., Popkova, E.G. (eds) Industry 4.0 . Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-75405-1_21

Elguindi, J., Hao, X., Lin, Y., Alwathnani, H. A., Wei, G., & Rensing, C. (2011). Advantages and challenges of increased antimicrobial copper use and copper mining. Applied Microbiology and Biotechnology, 237-249.

El Bazi, N., El Hadraoui, H., Laayati, O., El Maghraoui, A., Chebak, A. Mabrouki, M. (2023). Digital Twin in Mining Industry: A Study on Automation Commissioning Efficiency and Safety Implementation of a Stacker Machine in an Open-Pit Mine. Conference: 2023 5th Global Power, Energy and Communication Conference (GPECOM) June 2023. DOI: 10.1109/GPECOM58364.2023.10175788

Fekete, J. (2015). Big data in mining operations. Master's Thesis Copenhagen Business School.

Feng, X., & Carvelli, V. (2022). Additive manufacturing technology in mining engineering research. Deep Underground Science and Engineering 2022;1:15–24. DOI: 10.1002/dug2.12014

Flynn, J., Dance, S., & Schaefer, D. (2017). Industry 4.0 and its potential impact on employment demographics in the UK. Advances in Transdisciplinary Engineering, 6, 239-244.

Fundación Chile. (2019). Caracterización de proveedores de la minería chilena. Santiago: Fundación Chile.

Fundación Chile. (2016). Casos de Innovación de Proveedores en la Minería Chilena. Santiago: Fundación Chile.

Fundación Chile. (2017). Casos de Innivación de Proveedores en la Minería Chilena. Santiago: Fundación Chile.

Fundación Chile. (2018). Casos de Innovación de Proveedores en la Minería Chilena. Santiago: Fundación Chile.

Fundación Chile. (2021). Casos de Innovación de Proveedores en la Minería Chilena. Santiago: Fundación Chile.

Fundación Chile. (2022). Casos de Innovación de Proveedores en la Minería Chilena. Santiago: Fundación Chile.

Gaber, T., El Jazouli, Y., Eldesouky, E., Ali, A. (2021). Autonomous Haulage Systems in the Mining Industry: Cybersecurity, Communication and Safety Issues and Challenges. Electronics 2021, 10,1357. https://doi.org/10.3390/electronics10111357

Geldes, C. (2023). Challenges of Industry 4.0 for Companies in Emerging Economies: Some Inputs for the Research. J. Technol. Manag. Innov. 18 (3), 3-4.

Geldes, C. Castillo-Vergara, M., Muñoz-Cisterna, V. (2023). Desafíos de la Industria 4.0 en las PYMES. Observatorio Económico. 184: 14-16. DOI: https://doi.org/10.11565/oe.v1i184.536

Görmüş, A. (2019, March). Future of work with the industry 4.0. In International Congress on Social Sciences (INCSOS 2019) Proceeding Book (Vol. 1, No. 32, pp. 317-323).

Heredia, J., Castillo-Vergara, M., Geldes C., Carbajal Gamarra F., Flores, A., & Heredia, W. (2022). How do digital capabilities affect firm performance? The mediating role of technological capabilities in the "new normal". Journal of Innovation & Knowledge, 7 (2). https://doi.org/10.1016/j.jik.2022.100171.

Hirman, M., Benesova, A., Steiner, F., & Tupa, J. (2019). Project management during the Industry 4.0 implementation with risk factor analysis. Procedia Manufacturing, 38, 1181-1188.

Hodge, R.A., Ericsson, M., Löf, O., Löf, A., Semkowich P. (2022).The global mining industry: corporate profle, complexity, and change. Mineral Economics (2022) 35:587–606

Hughes, M. (2016). Precariedad laboral en Chile. Prácticas de resistencia en los sindicatos de trabajadores tercerizados de la Gran Minería Chilena. Revista de Estudios Marítimos y Sociales. Nº 10 - Diciembre de 2016

Instituto Nacional de Normalización de Chile. (2018). NCh-ISO31000:2018. Santiago: Instituto Nacional de Normalización de Chile.

Instituto Nacional de Normalización de Chile. (2020). NCh-ISO31010:2020 Gestión de riesgos – Técnicas de evaluación del riesgo. Santiago: Instituto Nacional de Normalización de Chile.

InvestChile. (2023, January). Chilean mining industry leads digital transformation. InvestChile. https://blog.investchile.gob.cl/chilean-mining-industry-digital-transformation

Jha, A., Young, A. & Sattarvand, J. (2023). Blockchain Technology and Mining Industry: A Review. Mining, Metallurgy & Exploration 40, 2269–2280 (2023). https://doi.org/10.1007/s42461-023-00874-3

Jiskani, I., Zhou, W., Hosseini, S., & Wang, Z. (2023). Mining 4.0 and climate neutrality: A unified and reliable decision system for safe, intelligent, and green & climate-smart mining. Journal of Cleaner Production, 13.

Kagan, E., Goosen, E., Pakhomova, E., & O., G. (2021). Industry 4.0. and an upgrade of the business models of large mining companies. IOP Conf. Series: Earth and Environmental Science, 1-10.

Koropets, O. A., & Tukhtarova, E. K. (2021). The impact of advanced industry 4.0 technologies on unemployment in Russian regions. Ekonomika Regiona= Economy of Regions, (1), 182.

Kunhahamed, P., & Rajak, S. (2023). Application of Blockchain in Mining 4.0. En N. Suyel, & A. Kemal, Blockchain and its Applications in Industry 4.0 (págs. 123-137). Patna, India: Springer.

Kurt, R. (2019). Industry 4.0 in terms of industrial relations and its impacts on labour life. Procedia computer science, 158, 590-601.

Kurzweil, R. (2005). The Singularity Is Near: When Humans Transcend Biology. New York: Penguin Books.

Kuzior, A. (2022). Technological Unemployment in the Perspective of Industry 4.0. Virtual Economics, 5(1), 7-23

Leiva, S. & Campos, A. (2013). Movimiento social de trabajadores subcontratados en la minería privada del cobre en Chile. Psicoperspectivas, 12(2), 51-61. doi:10.5027/PSICOPERSPECTIVAS-VOL12-ISSUE2-FULLTEXT-293

Lööw, J., Abrahamsson, L., & Johansson, J. (2019). Mining 4.0—the Impact of New Technology from a Work Place Perspective. Mining, Metallurgy & Exploration, 36, 701–707.

Lund, E., Pekkari, A., Johansson, J., & Joel, L. (2024). Mining 4.0 and its effects on work environment, competence, organisation and society – a scoping review. Mineral Economics, 1-15.

Minería Chilena (2021). Informe Técnico: Drones en minería: un valor agregado para realizar nuevas tareas. Julio 2021, Nº 481, 43-45

Meller, P. (2019). Cobre chileno: productividad, innovación y licencia social. Santiago: Cieplan Utalca Banco de Desarrollo de América Latina.

Muniz Jr, J., Ramalho Martins, F., Wintersberger, D., & Oliveira Santos, J. P. (2023). Trade union and Industry 4.0 implementation: two polar cases in Brazilian trucks manufacturing. Journal of Workplace Learning, 35(8), 670-692.

Natarajan, A. (2022). Reference Class Forecasting and Machine Learning for Improved Offshore Oil and Gas Megaproject Planning: Methods and Application. Project Management Journal, 456-484.

Nguyen, L.Q., Bui, L.K., Ngoc Q. B., & ·Tran, T. X. (2023). Advances in Geospatial Technology in Mining and Earth Sciences, Environmental Science and Engineering, https://doi.org/10.1007/978-3-031-20463-0_1

Noriega, R., Pourrahimian,Y. (2022).A systematic review of artificial intelligence and data-driven approaches in strategic open-pit mine planning. Resources Policy, Volume 77, 102727. DOI: 10.1016/j.resourpol.2022.102727

Okada, K. (2022). Breakthrough technologies for mineral exploration. Miner Econ 35, 429–454. https://doi.org/10.1007/s13563-022-00317-3

Oliveira Cruz, C, & da Cunha Rodovalho, E. (2019). Application of ISO 31000 standard on tailings dam safety. REM, Int. Eng. J., Ouro Preto, Special Supplement 1, 72(1), 47-54. http://dx.doi.org/10.1590/0370-44672018720123

Pałaka, D., Paczesny, B., Gurdziel, M., & Wieloch, W. (2020). Industry 4.0 in development of new technologies for underground mining. In E3S Web of Conferences (Vol. 174, p. 01002). EDP Sciences.

Peña Ramírez, C., Alegría, H., & Rios Muñoz, F. (2022). Modelo de análisis de riesgos de contratos en minería ante Industria 4.0. Journal of Management & Business Studies, 1-16.

Pérez, D. (2022). Reinterpretando el sindicalismo tercerizado minero en Chile. Una perspectiva marxista territorial de la subcontratación. DADOS, Rio de Janeiro, vol.65 (2): e20200307, 2022. https://doi.org/10.1590/dados.2022.65.2.264

Phibrand. (2021). The 3rd Ranking of Providers of the Mining Industry in Chile. Phibrand, https://www.phibrand.com/wp-content/uploads/2021/05/Third-Ranking-of-Mining-Suppliers_summary-report.pdf

Prochile. (2022). Reporte Anual Proveedores Mineros – 2022. Reporte de exportaciones de los proveedores mineros. Dirección estudios – SUBREI. https://www.subrei.gob.cl/estudios-y-documentos/documentos/detalle-otras-fichas-y-reportes/reporte-anual-proveedores-mineros---2022

Ríos Muñoz, F., Peña Ramírez, C., Meza, J., & Crouch, T. (2024). Platinum Group Metals Extraction from Asteroids vs Earth: An Overview of the Industrial Ecosystems, Technologies and Risks. Accepted in Mineral Economics, 37. https://doi.org/10.1007/s13563-024-00429-y

Rupprecht, S.M. (2015). Owner versus contract miner - A South African update. J. S. Afr. Inst. Min. Metall. 115 (11) 1021-1025. http://dx.doi.org/10.17159/2411-9717/2015/v115n11a6.

Rylnikova, M.; Radchenko, D.; Klebanof, D. (2017). Intelligent Mining Engineering Systems in the Structure of Industry 4.0. Moscow: Web of Conferences.

Saldana, M., Flores, V., Toro, N., & Leiva, C. (2019). Representation for a prototype of recommendation system of operation mode in copper mining. Coimbra, Portugal: IEEE.

Sam-Aggrey, H. (2020). Assessment of the Impacts of New Mining Technologies: Recommendations on the Way Forward. WIT Trans. Ecol. Environ, 245, 177-187.

Sánchez, F., & Hartlieb, P. (2020). Innovation in the Mining Industry: Technological Trends and a Case Study of the Challenges of Disruptive Innovation. Mining, Metallurgy & Exploration, 1385-1399.

Schwab, K. (2016). La cuarta revolución industrial. Madrid: Debate.
Sicep. (2023). Reporte barometro de proveedores de la industria minera 2023. Available from https://sicep.cl/RicardoM/v/BAROMETRO.pdf. Antofagasta: Sicep.

Simensen, H. & Perry, J. (1999). Risk identification, assessment and management in the mining and metallurgical industries. Journal of the Southern African Institute of Mining and Metallurgy, 99(6), 321-329.

Sishi, M., & Telukdarie, A. (2022). Implementation of Industry 4.0 technologies in the mining industry – a case study. Int. J. Mining and Mineral Engineering, 11(1), Johannesburgo.

Skenderas, D.,& Politi, C. (2023). Industry 4.0 Roadmap for the Mining Sector. Mater. Proc. 2023, 15, 16. https://doi.org/10.3390/materproc2023015016

Smith, K., & Sepasgozar, S. (2022). Governance, Standards and Regulation: What Construction and Mining Need to Commit to Industry 4.0. Buildings, 1-23.

Stojanova, H., Lietavcova, B., & Vrdoljak Raguž, I. (2019). The Dependence of Unemployment of the Senior Workforce upon Explanatory Variables in the European Union in the Context of Industry 4.0. Social Sciences. 8(1):29. https://doi.org/10.3390/socsci8010029

Szabó-Szentgróti, G., Végvári, B., & Varga, J. (2021). Impact of Industry 4.0 and digitization on labor market for 2030-verification of Keynes' prediction. Sustainability, 13(14), 7703.

Thomas, S., & Tang, Z. (2010). Labour-intensive construction subcontractors: Their critical success factors. International Journal of Project Management, 738-740.

Thomas, S., Tang, Z., & Palaneeswaran, E. (2009). Factors contributing to the success of equipment-intensive subcontractors in construction. International Journal of Project Management, 736-744.

Tkachuk, V., Yechkalo, Y., Brovko, D., Sobczyk, W.(2023). Augmented and Virtual Reality Tools in Training Mining Engineers. Journal of the Polish Mineral Engineering Society, January 2023.

Torres, R. Á. (2015). Gestión de contratos de servicios a la minería. Santriago: Universidad de Chile.

Tubis A., Werbi ´nska-Wojciechowska S.& Wroblewski A. (2020). Risk Assessment Methods in Mining Industry—A Systematic Review. Applied Sciences, 10(15), 5172.

Tupa, J., Simota, J., & Steiner, F. (2017). Aspects of risk management implementation for Industry 4.0. Procedia manufacturing, 11, 1223-1230.

Uğurlu, K., & Pajo, A. (2019). A Measure Against Unemployment Problem Expected to Occur by Industry 4.0: Cittaslow. Seyahat Ve Otel İşletmeciliği Dergisi, 16(1), 167-185. https://doi.org/10.24010/soid.538540

Ulewicz, R., Krstić, B. & Ingaldi, M. (2022).Mining Industry 4.0 – Opportunities and Barriers. Acta Montanistica Slovaca, Volume 27 (2), 291-305.

Van Hau, N., Khanh Ly, C. T., Quynh Nga, N., Hong Duyen, N. T., & Huong Hue, T. T. (2022). Digital Transformation in Mining Sector in Vietnam. Inżynieria Mineralna, (2).

Vergara, C. (2012). Competitividad mundial en el mercado del cobre. Tesis de magíster en minería, Universidad de Chile. https://repositorio.uchile.cl/bitstream/handle/2250/112543/cf-vergara_cv.pdf?sequence=1&isAllowed=y

Vidal Véjar, R. E. (2021). Variables críticas en la administración de contratos en proyectos mineros (Doctoral dissertation, Universidad del Desarrollo. Facultad de Ingeniería).

Voronov, Y., Voronov, A., & Makhambayev, D. (2020). Current State and Development Prospects of Autonomous Haulage at Surface Mines. E3S Web of Conferences 174, 01028 (2020) Vth International Innovative Mining Symposium. https://doi.org/10.1051/e3sconf/202017401028

Whyte, J. (2019). How Digital Information Transforms Project Delivery Models. Project Management Journal, 50(2), 177-194.

World Bank. (2020). Using Blockchain to Support the Energy Transition and Climate Markets : Results and Lessons from a Pilot Project in Chile. Washington: World Bank.

World Economic Forum. (2017). Digital Transformation Initiative Mining and Metals Industry. Davos Klosters: World Economic Forum.

Zhang, G.,Chen., C.,Cao, X.,Zhong, R.,Duan, X,.& Li, P.(2022). Industrial Internet of Things-enabled monitoring and maintenance mechanism for fully mechanized mining equipment. Advanced Engineering Informatics. Advanced Engineering Informatics, Volume 54, October 2022, 101782

Zhironkina, O. and Zhironkin, S. (2023). Technological and Intellectual Transition to Mining 4.0: A Review. Energies, 16, 1427. https://doi.org/10.3390/en16031427

9. Annexes

Table N° Ia. Maximum technological level identified in extraction process (Consejo Minero, 2018).

Process	Subprocess	Equipment	Suppliers	Maximum technological level identified
Extraction	Exploration and drilling	Drilling machine	Sandvink Atlas Copco Boart Longyear	Teleoperated
	Open pit extraction	Drilling machine	CAT Sandvik Atlas Copco Komatsu	Teleoperated
		Shovels	CAT Sandvik Liebherr	Manual operation
		Front loader	CAT Komatsu	Manual operation
		Trucks	CAT Komatsu	Autonomous
		Bulldozer	CAT Komatsu Liebherr	Manual operation
		Dispatch system	CAT Modular Jiwsaw	Monitoring, visualization
		Safety equipment	Modular	Monitoring, visualization
		Satellite positioning, GPS	Komatsu	Monitoring, visualization
		Equipment vital signs	CAT Komatsu	Monitoring, visualization
		Gyratory crusher	Metso Sandvik FLSmidth	Automated
		Jaw crusher	Metso Sandvik FLSmidth	Semiautomated
		Cone crusher	Metso Sandvik	Automated
		Control system	Sandvik	Automated
	Underground extraction	LHD	CAT Komatsu Atlas Copco Sandvik	Teleoperated
		Production jumbo	Komatsu Atlas Copco Sandvik	Teleoperated
		Rock breaker	Sandvik Atlas Copco BTI Brokk	Teleoperated
		Belts	Good year Phoenix Contitech Bridgestone	Monitoring, visualization
		Dumper	CAT Sandvik Komatsu Atlas Copco	Manual operation
		Locomotive	Ferroestatal Kiruna	Semiautonomous
	Blasting	Factory truck	Enaex Orica	Teleoperated

ISSN: 0718-2724. (http://jotmi.org)

Table N° Ib. Maximum technological level identified in extraction process (Consejo Minero, 2018).

Process	Subprocess	Equipment	Suppliers	Maximum technological level identified
Processing	Concentrate process	Rod mill	Metso	
		Ball mill	Metso	Automated
			FLSmidth	
		SAG mill	Metso	
			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	
		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	

Table N° Ic. Technologies available to be implemented in the short or medium term (Center for Copper and Mining Studies, 2020).

Stage of Value Chain	Process	Technologies	Probability of Implementation 2020-2022[14]
Geology, Exploration and Extraction	Geochemistry	Multivariate analysis	3
		Online geotechnical monitoring	4
	Geotechnics	Using AI to filter alarms (expert assistance)	3
		Ore deposit Simulation	3
		On-site information capture	2
		Capture of geophysical information (dronnes)	2
	Drilling / Geology	Geological modeling	1
		Advanced modeling	3
	Drilling	On-site sample analysis	2
		Autonomous operation	2
		New materials for drill bits	4
		Advanced modeling	3
	blasting	Smart loading of explosives	2
Mineral Transport		On-site information capture	3
		Autonomous operation (front loaders)	1
		Semi-autonomous operation	3
		Assisted operation	3
	loading	New wear elements	
		Operation training	3
		Electric equipment	4
		Online information capture	3
	Transportation	Autonomous operation	2
		Operation training	3
		Hybrid equipment (trolley assist)	1
		Fuel cells	1
		Electric equipment	2
Processing		Image recognition	2
		Online measurement of performance	2
		Remote monitoring and diagnostics (sensors)	2
	Crushing	Remote operation	
		New wear elements	
		Regenerative belt	2
		Online monitoring	3
		online measurement of performance	3
		Remote monitoring and diagnostics (sensors)	3
		Remote operation	3
	Grinding	Expert system / Machine learning	2
		Robotic arm for changing shell lining / Bolting	2
		New materials for balls	
		Online monitoring	3
	Flotation	Expert system / Machine learning	2
		Online monitoring	2
	Leaching	Monitoring of Heap leaching (drones)	1
		Bioleaching of sulfides	1
	Solvent Extraction	Online monitoring	2
		Online monitoring	2
	Electrowinning	Robotic cathode stripper	4

[14]Probability 1: It is unlikely that technology be implemented in the next three years. Probability 2: It is possible that technology be implemented in the next three years. Probability 3: It is likely that technology be implemented in the next three years. Probability 4: It is almost certain that technology be implemented in the next three years.

Process Management and Support		SAP/ERP	4
		Automated distribution center	1
		Online performance measurement	2
		Remote monitoring and diagnostics (sensors)	1
		Remote operation	
		Use of renewable energy	4
	Logistics	Transportation of personnel using electric vehicles	3
		Minehub	1
		WEF for traceability	2
	Economic evaluation	Monte Carlo simulation	
	Permissions	Online monitoring and assisted operation (smelters and mine dust)	4
	Projects	Printing of elements for modular construction	1
		Condition monitoring (predictive)	3
		Predictive failure models	2
	Maintenance	Use of drones to send spare parts	1
		Metal 3D printing of spare parts	1
		Training and execution of maintenance	2
Health, Safety, Environment & Communities	Dewatering	Hydrogeological modeling	3
		Condition monitoring (predictive)	2
	Mine Services	Biocementation	3
		Seismic monitoring	3
		Active control (collision avoidance systems)	2
	Health & Safety	Smartcap	3
		Smart vests	3
	Tailings	Online monitoring of dam stability	3
	Closure / Remediation	Water acidity monitoring	1

Table N° Id. Supplier and contractors companies (%) which claim to be developing trends technology in mining (Fundación Chile, 2019).

Technology/ Productive Area	Geology & Exploration	Mining planning	Open pit mining	Undergroung mining	Concentration	Tailing	Hydrometallurgy	Smelting	Refining	Commercialization	New copper applications	Tranversal
Digital reality	7	14	18	15	18	15	15	12	9	6	4	19
Digital twins	9	14	25	17	26	21	21	9	10	8	5	14
Big Data	8	19	27	22	23	22	19	12	11	11	4	15
Machine Learning	9	11	20	15	19	20	19	11	9	8	5	18
Governance & data management	10	18	24	19	22	22	23	12	11	11	5	16
Blockchain	4	9	16	14	9	10	12	9	8	4	3	10
Robotic	8	19	25	22	16	14	18	9	10	9	2	15
Cloud	8	14	23	19	24	17	21	16	12	9	5	19
Digital transformation	10	17	27	21	26	19	24	9	9	11	4	20
Sensors & IoT	11	14	26	23	23	15	28	19	13	12	2	12
Average	**8.4**	**14.9**	**23.1**	**18.7**	**20.6**	**17.5**	**20**	**11.8**	**10.2**	**8.9**	**3.9**	**15.8**

Table N° Ie. Summary of Contracts Statistics classified by productive area.

Geology and Extraction	**Staffing**	**Cost (USD)**	**Duration (Days)**
Max	288	4.000.000	1.913
Min	1	700.000	457
Median	8	1.000.000	1.188
Average	33	1.515.517	1.270
Stantard Deviation (SD)	61	716.424	428
Obs	58	58	58

Mineral Transport	**Staffing**	**Cost (USD)**	**Duration (Days)**
Max	335	10.000.000	1.826
Min	2	1.000.000	740
Median	99	2.000.000	1.779
Average	112	3.764.706	1.613
Stantard Deviation (SD)	100	3.072.650	307
Obs	17	17	17

Processing	**Staffing**	**Cost (USD)**	**Duration (Days)**
Max	1.247	12.000.000	1.979
Min	1	500.000	365
Median	5	1.000.000	1.429
Average	25	1.601.186	1.330
Stantard Deviation (SD)	83	1.166.581	433
Obs	253	253	253

Process Management	**Staffing**	**Cost (USD)**	**Duration (Days)**
Max	37	3.500.000	1.825
Min	2	700.000	730
Median	4	900.000	1.096
Average	12	1.270.000	1.232
Stantard Deviation (SD)	15	873.117	325
Obs	10	10	10

Maintenance Services	**Staffing**	**Cost (USD)**	**Duration (Days)**
Max	163	6.000.000	1.971
Min	1	500.000	487
Median	4	1.000.000	1.461
Average	14	1.515.493	1.350
Stantard Deviation (SD)	30	955.233	460
Obs	71	71	71

Projects and Construction	**Staffing**	**Cost (USD)**	**Duration (Days)**
Max	1.029	10.000.000	1.913
Min	1	500.000	275
Median	12	1.000.000	1.279
Average	62	1.770.940	1.291
Stantard Deviation (SD)	176	1.500.635	415
Obs	117	117	117

General Management	**Staffing**	**Cost (USD)**	**Duration (Days)**
Max	736	11.000.000	1.947
Min	1	500.000	261
Median	5	1.000.000	1.460
Average	29	1.557.377	1.390
Stantard Deviation (SD)	96	1.236.211	408
Obs	244	244	244

Figure N° A1. Normal distribution for staffing.

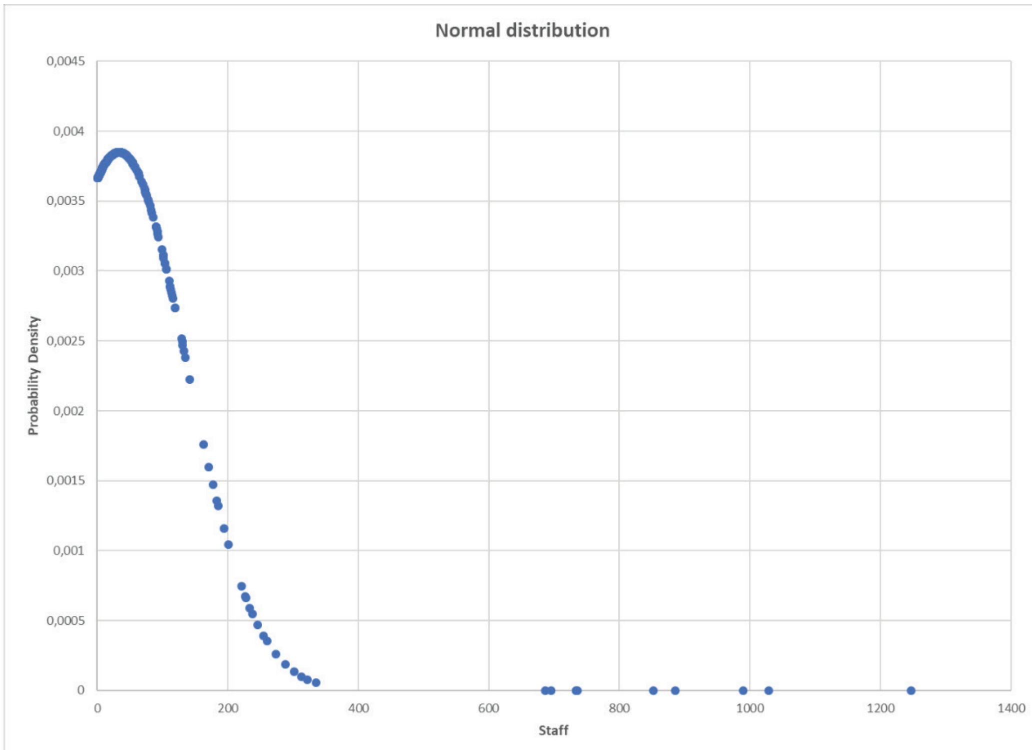


Figure N° A2. Normal distribution for contracts cost.

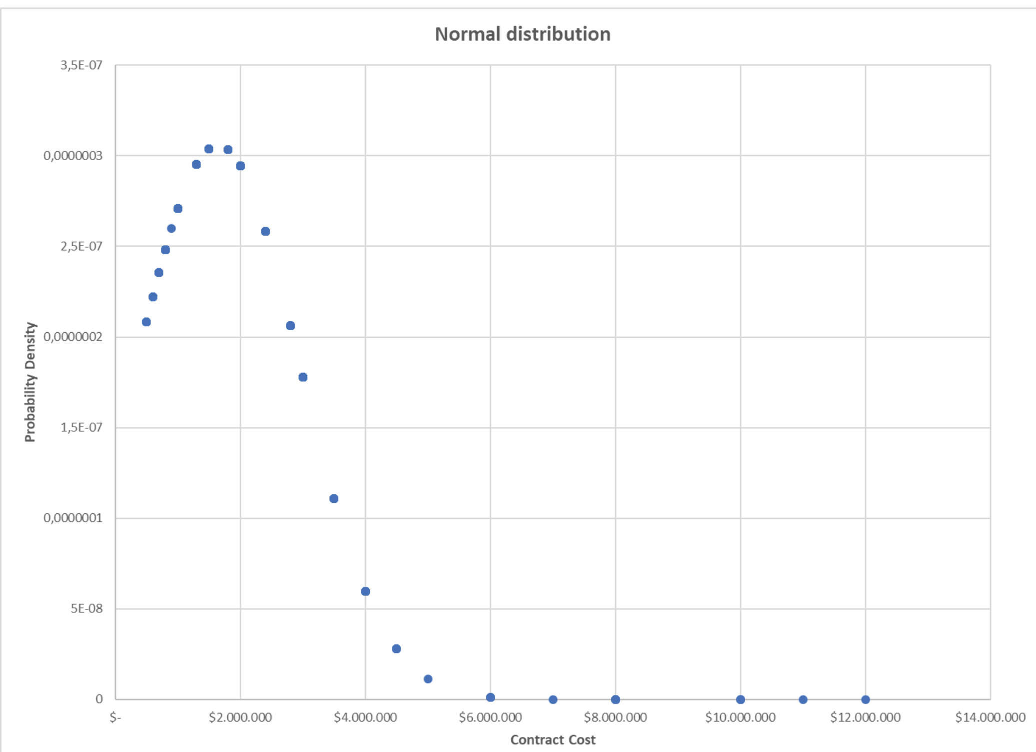


Figure N°A3. Normal distribution for contracts duration.

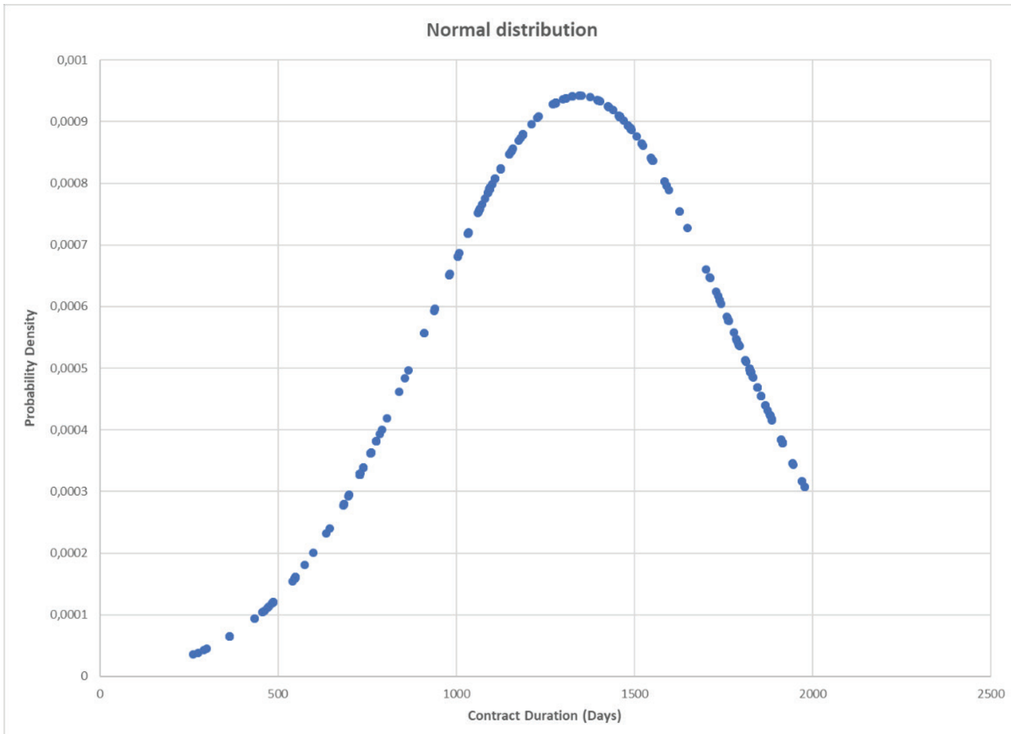
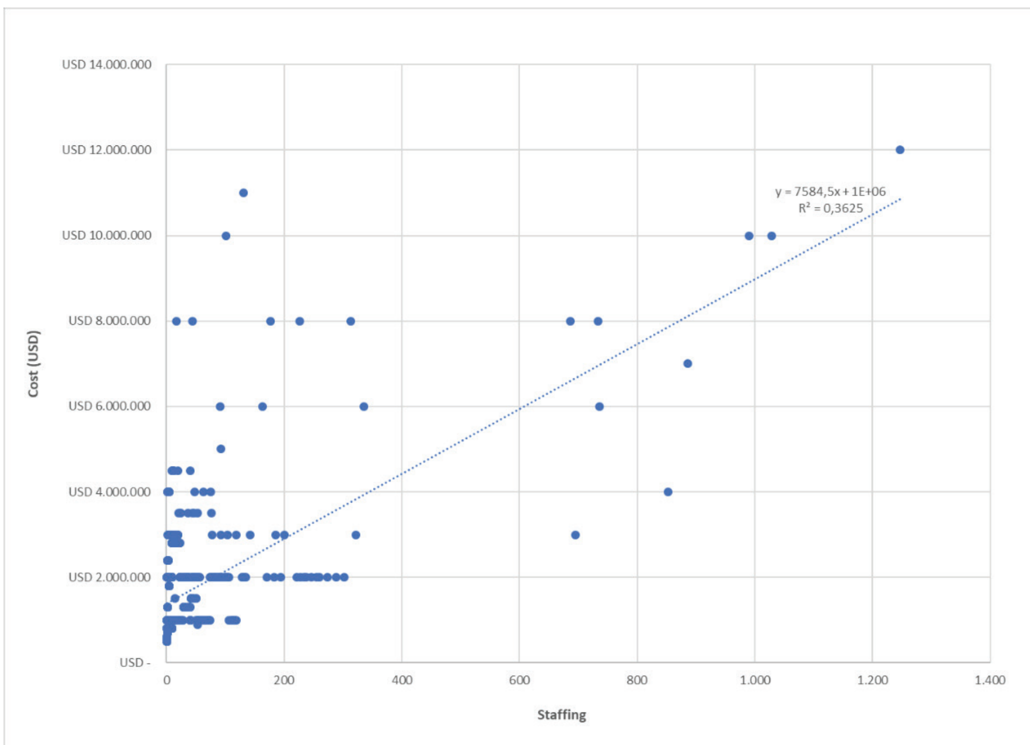


Figure N° A4. Correlation between Staffing and contracts' cost.



ISSN: 0718-2724. (http://jotmi.org)

Figure N° A5. Correlation between Staffing and contracts duration.

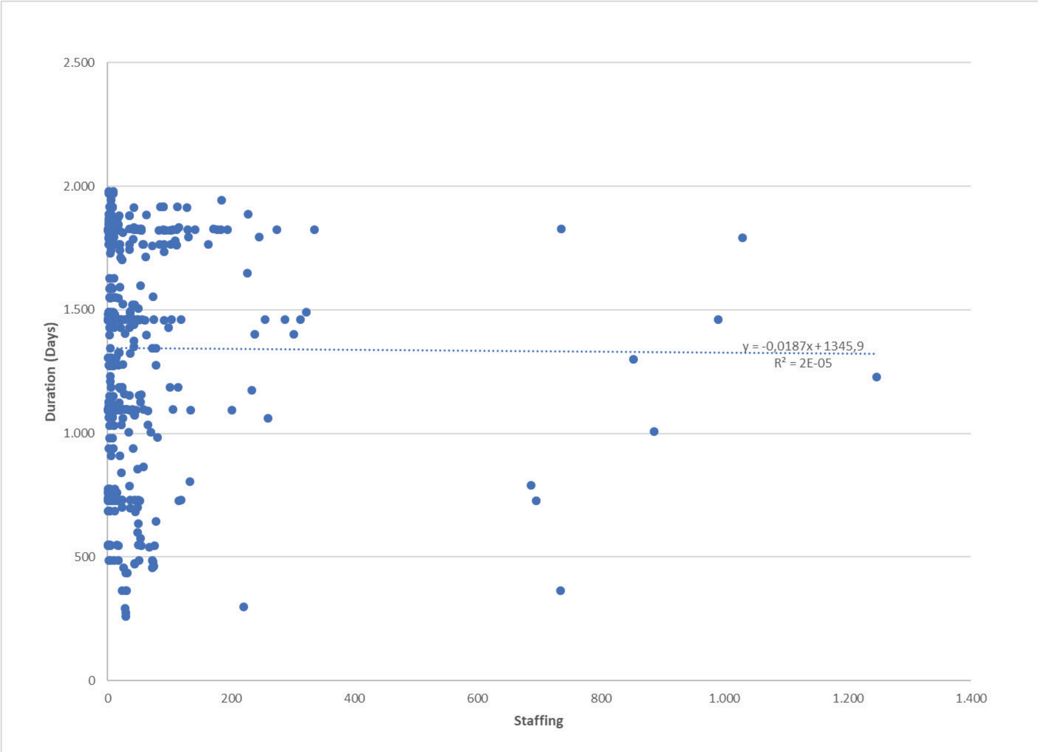
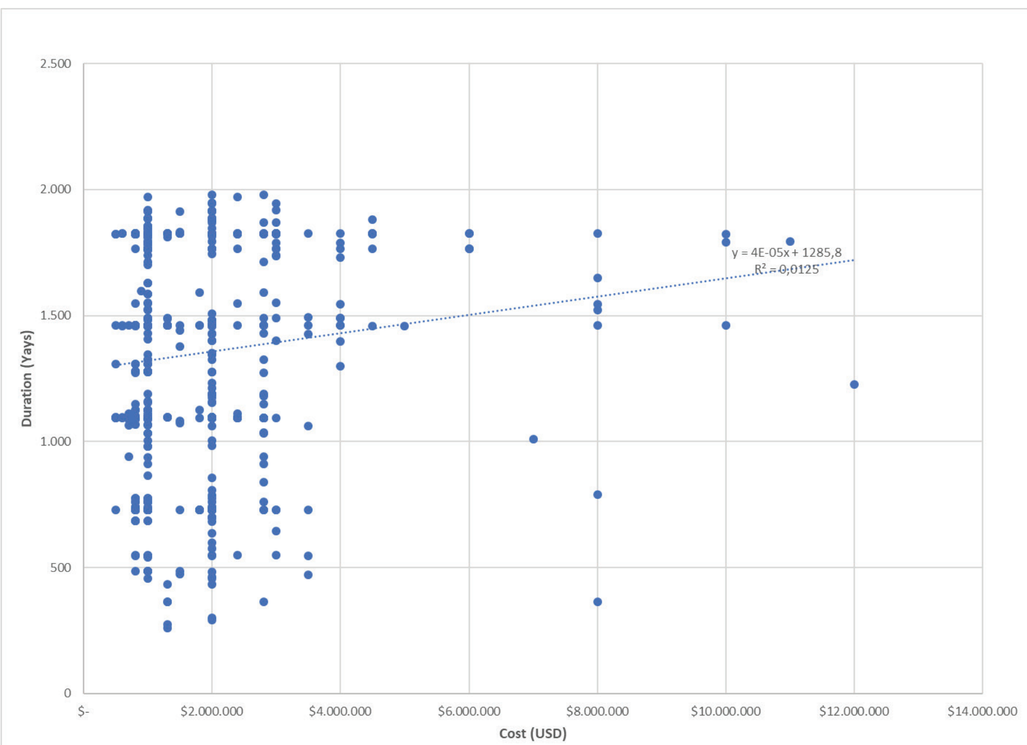


Figure N° A6. Correlation between cost and contracts duration.



ISSN: 0718-2724. (http://jotmi.org)

10. Appendix

10.1. Risk Assessment Methods Used in Mining Industry

The mining industry is increasingly focusing on risk assessment and management, with a growing interest in both human factor and strategic aspects. However, there is a lack of research on systematic literature reviews and surveys that address these risk aspects simultaneously. Tubis et al. (2020) develop a literature review on analysis, assessment, and risk management in the mining sector, based on a human engineering system. In this context, some risk assessment methods used in the mining industry include the Monte Carlo method for risk analysis (Alves Cantini et al., 2022; Simensen, H. & Perry, J., 1999).

Nevertheless, an approach for risk management was given by Domingues et al. (2017), where the authors, based on the ISO 31,000:2009 standard, used and proposed a tool for complex system investigations. In this regard, ISO international standards 31000:2009 and also 9,001:2015 emphasize the importance of risk management in directing an organization and controlling risks that can affect its objectives. In this regard it is possible examples about the use of this standard. For instance, Oliveira Cruz and da Cunha Rodovalho (2019) discuss the application of ISO 31,000 for tailings dam safety.

10.2. Risk Assessment Methods Used in Industry 4.0

Despite the relevance of Chile's mining industry, risk models applied to industry 4.0 integration in contracts have not been intensively developed. Some examples found in the literature related to risk assessment methods used in industry 4.0 include Birkel et al. (2019), who present a framework of risks related to Industry 4.0, focusing on the Triple Bottom Line of sustainability. It outlines economic risks, ecological risks, social risks, technical risks, IT-related risks, and legal and political risks. On the other hand, Hirman et al. (2019) examine the implementation of Industry 4.0 in companies, focusing on the project framework. They outline the basic principles and seven phases of the process, discusses current project management, defines the implementation phase description and methodology, and provides recommendations for small, medium, and large companies in reducing risk. Tupa et al. (2017) research key aspects of Industry 4.0 and present a framework for implementing risk management for this concept, considering data volume and availability enhancements.

10.3. ISO 31000:2009 Standards

It should be noted that risk management, as defined by ISO 31,000:2009, requires models or theories to guide activities. Thus, an effective risk management must be operational within complex systems, as demonstrated in R&D environments.

The National Standardization Institute of Chile (Instituto Nacional de Normalización, 2018) carried out a study and preparation of technical regulations at national level, which developed an adjustment to ISO 31,000 standard through its technical risk management committee. The standard was originally created by the International Organization for Standardization (ISO) in order to globally address the risk management of organizations, regardless of the organization size, the market in which company operates or the source of its capital. Thus, ISO 31,000 basically does not focus on particular risks as specific standards. These regulations specify different types of risks that organizations and their collaborators could face. In this way, a concept of risk management is defined, with the aim of drawing a horizon and determining the aspects to be managed, their probabilities of occurrences and the consequences of these.

Subsequently, a series of tools are defined from which it is possible to choose the most appropriate according to the sector or specialty, to carry out a correct risk analysis. It should be noted that among these methodologies, there are qualitative, quantitative and semi-quantitative methods.

Although for this item specification the support standard is also used, ISO 31,010 has a varied number of techniques. In this way, the most appropriate can be chosen according to the type of risk that is to be evaluated and mitigated, according to the consequences, probabilities, effectiveness of existing controls and / or estimation of the level of risks to be faced (Instituto Nacional de Normalización, 2020).

It should be mentioned that these regulations have not been designed for certification purposes, nor for regulatory uses governed by them, rather they seek to be a source of generic information for a proper risk management according to the organization needs.

10.4. Methodology Used for Developing a Risk Model

The study of Nch-ISO 31,000 standards on Risk management - Analysis and implementation, and Nch-ISO 31,010, risk management - Risk assessment techniques was carried out by Peña -Ramírez et al. (2022). With the aim of a better understanding of the different risk management systems, and looking for the most appropriate methods to carry out a correct risk assessment according to the project requirements, the following techniques were chosen.

Regarding the contracts pre-selection to be evaluated, the use of a consequence / probability matrix was considered, adapted to particular needs of this business case.

Then, for the service proposal forms implementation by the contractor and pre-selection by the contract administrator, a combination of "scenario analysis" and "business impact analysis" techniques were used. Thus, these techniques was designed to achieve the best benefits for the organizations that implement this methodology because of they allow estimating from different points of view the possible consequences of options.