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ScruMine: Optimizing mineral extraction with agile methodologies and LLM

ScruMine: Optimizando la extracción de minerales con metodologías ágiles y LLM

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ABSTRACT

The mining industry, which is fundamental to the global economy due to its extraction of natural resources and supply of essential raw materials for various industries, faces ongoing challenges in terms of efficiency, productivity, and sustainability. Although significant technological advancements have been implemented, including automation, artificial intelligence, and machine learning, integrating agile methodologies in mining extraction processes still needs to be explored. This article presents an approach that combines SCRUM methodology with advanced artificial intelligence technology to optimize material extraction management in mining operations. We propose a model where each element of the extraction process becomes part of the SCRUM team, with a Large Language Model (LLM) acting as the SCRUM Master and a Mining Operations Engineer as the Product Owner. We detail the team structure, adapted SCRUM processes, necessary technological implementation, and daily workflow.

Keywords: Mining, SCRUM, process optimization, material extraction, agile methodologies, artificial intelligence.

RESUMEN

La industria minera, fundamental para la economía global por su extracción de recursos naturales y suministro de materias primas esenciales para diversas industrias, enfrenta desafíos continuos en eficiencia, productividad y sostenibilidad. Aunque se han implementado avances tecnológicos significativos, incluyendo automatización, inteligencia artificial y aprendizaje automático, la integración de metodologías ágiles en los procesos de extracción minera permanece inexplorada. Este artículo presenta un enfoque que combina la metodología SCRUM con tecnología avanzada de inteligencia artificial para optimizar la gestión de extracción de material en operaciones mineras. Proponemos un modelo donde cada elemento del proceso de extracción se convierte en parte del equipo SCRUM, con un Modelo de Lenguaje Grande (LLM) actuando como SCRUM Master y un Ingeniero de Operaciones Mineras como Product Owner. Detallamos la estructura del equipo, los procesos adaptados de SCRUM, la implementación tecnológica necesaria y el flujo de trabajo diario.

Palabras clave: Minería, SCRUM, optimización de procesos, extracción de materiales, metodologías ágiles, inteligencia artificial.

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INTRODUCTION

Mining plays a fundamental role in the global economy, providing essential raw materials for various industries and economic activities. Its contribution to Gross Domestic Product (GDP) is significant in numerous countries, both developed and developing, generating national income, creating jobs, and fostering infrastructure development [1], [2].The mining industry occupies a central position in the global supply chain, supplying crucial resources for manufacturing, construction, and energy production sectors. The production and export of minerals remain a key economic pillar for many countries. As of the 2020s, in Peru, this represents 10% of GDP [3]; in Australia, 9% [4]; in South Africa, 7%; and in Canada, 4% [5]. These countries significantly depend on extracting resources such as copper, gold, iron, and coal for economic growth and exports. In the same context, the mining sector's contribution to Chile's GDP is substantial, with copper being the main export product [6]. Chile remains the world's largest copper producer, producing 1,325 million metric tons in 2023 [7]. Additionally, the country is experiencing a boom in lithium demand, which has put the salt flats of northern Chile in the global spotlight [6], [8]. However, the Chilean mining sector faces challenges in increasing efficiency, productivity, and sustainability while focusing on reducing its carbon footprint and protecting the environment [9].

The mining industry has undergone significant technological advancements in recent decades, driven by the need to enhance productivity, safety, and environmental sustainability. Modeling technologies have become crucial for optimizing open-pit mining operations, highlighting a lower environmental impact through more efficient work processes and predictive analysis capabilities [10], [11]. The adoption of technologies such as automation, artificial intelligence (AI), machine learning (ML), and the Internet of Things (IoT) has provided new visions of operations in mining [12], being used in various areas, including sonic drilling, microwave radar surveillance, and radon gas monitoring, among other applications [13]. Initially introduced with autonomous trucks, AI, ML, and autonomous technologies have provided economic benefits by reducing costs and improving worker safety. However, their implementation faces various challenges, including economic and social factors[14], where they must adopt the principles established for Industry 4.0 and 5.0, thus maintaining and facing future challenges, including the transition to "green mining," a collaboration of workers with technologies, and improving occupational safety [15], [16].

Extraction processes naturally vary according to the type of mineral and the geological conditions of the deposit. The most common methods include open-pit mining and underground mining. Open-pit mining is primarily used for deposits near the surface. On the one hand it involves the removal of large quantities of material through the use of explosives and heavy machinery, followed by crushing and grinding processes. On the other hand, underground mining is employed to access deeper deposits, requiring the construction of tunnels and chambers to reach mineral deposits. Methods such as long-hole stopping and paste backfill are used to ensure stability [17]. These processes have undergone significant technological evolution in recent years, focusing on improving efficiency, safety, and environmental sustainability [18]. Among the most notable advances are the development of advanced treatments such as the use of microwaves, ultrasonic processing, and biological methods [19], as well as the introduction of new chelating agents and flotation reagents to improve metal extraction from low-grade ores [20]. The industry has also integrated advanced technical solutions, such as improved use of explosive energy and microbiological recovery [21], and implemented partially autonomous systems to optimize extraction and transportation [22], [23].

Additionally, solar installations for directly processing mining waste have been explored [24], and new multicomponent microflotation techniques have been developed [25]. The incorporation of robotic arms controlled by artificial intelligence and permanent magnet synchronous motors has improved the precision and efficiency of extraction, as indicated in [26]. Recent advances in mining truck automation have developed sophisticated programming models and algorithms that optimize energy consumption and temporal efficiency [27], [28]. These models integrate various factors such as loading requirements, spatial route coordination, and improvements in global search, thus refining decision-making processes for autonomous vehicles in open-pit mines. In parallel, significant innovations have been achieved in LiDAR point cloud registration algorithms. These improvements address the challenges of irregular terrains and detection inaccuracies within mining environments, resulting in more precise odometric calculations [29]. Additionally, real-time programming systems that employ tabu search algorithms and mixed integer programming models have been proposed. These systems seek to simultaneously optimize truck routes and speeds to minimize energy consumption in autonomous mining operations [28].

However, it is essential to note that, despite these technological advances, significant research or experiences have not yet been documented that explicitly focus on applying agile methodologies in the extraction process, integrating agility, technology, and technical personnel. Agile methodologies, originating in computer science, have revolutionized project management in various sectors, offering a flexible and adaptive approach that significantly contrasts with traditional methods [30]. In a business environment characterized by dynamism and rapid technological advancement, these methodologies have proven fundamental in efficiently responding to fluctuating market demands [31]. Agile frameworks, such as Scrum, Kanban, and Extreme Programming, prioritize collaboration, adaptability, and continuous value delivery, thereby improving efficiency and customer satisfaction. Their adoption has extended beyond software development, finding applications in sectors as diverse as healthcare [32], law development [33], and even the fashion industry [34]. Work teams adopting agile methodologies are characterized by autonomy, multifunctionality, and fluid communication. Daily meetings and periodic reviews promote transparency and alignment of objectives [35]. These teams can quickly respond to changes in project requirements, adjusting plans and priorities as needed, which improves collaboration and ensures that all members are aligned with project objectives. In the current context, agile methodologies are evolving to integrate emerging technologies, support decision-making tasks, predict outcomes, and automate repetitive tasks. Recent studies suggest that the implementation of agile methodologies has had a positive impact on optimizing industrial project management [35]. According to the NTTData report [36], they indicate that the surveyed mining sector shows a preference for team organization based on enablers, and their agile implementations are within work teams of administrative departments/cells of the mining companies and not in the productive or extraction processes, detailing a resistance to change when implementing agility.

This article presents an approach to improve mining operations processes by integrating the Scrum methodology in mineral extraction management, involving both machines and operators involved in this task. Here, a model is proposed where each element becomes an element of the SCRUM team, with a specifically trained Large Language Model (LLM) acting as the SCRUM Master. The system features a Mining Operations Engineer as the Product Owner, who defines goals based on production needs. The team structure, adapted SCRUM processes, necessary technological implementation, and daily workflow are described. This approach promises to improve operational efficiency, coordination, and real-time adaptability of mining operations, offering a transformative solution for the industry.

SCRUMINE FRAMEWORK

Current Situation

Currently, extraction processes in mining are characterized by significant complexity and dynamism, particularly in decision-making regarding exploitation areas [37]. The selection of zones for extraction is based on a multifactorial evaluation that includes detailed geological studies, mineral grade analysis, advanced mining planning, economic considerations, deposit accessibility, environmental and social impact assessments, and available technologies. Mining companies employ sophisticated computational models and optimization techniques to integrate these factors and determine the most efficient and profitable extraction plans [38]. The exploitation strategy is not limited to completely exhausting one area before moving to another; instead, it adopts a more flexible and dynamic approach [37]. Multiple work fronts are managed simultaneously with operations constantly optimized in response to market fluctuations, technological advances, and changing deposit conditions. This approach allows for maintaining a balance between the extraction of high and low-grade zones, ensuring the longevity of the mine and more stable production. The “cut-off grade” concept is dynamically adjusted according to economic and operational conditions, directly influencing extraction decisions [39]. This comprehensive and adaptive approach to mineral resource management reflects the complexity and sophistication of the modern mining industry, which seeks to maximize efficiency and long-term profitability while adapting to a constantly evolving operational and economic environment.

Proposed Situation

Integrating SCRUM methodology into material extraction management in mining operations represents an innovation in traditional extraction processes. This proposal adapts the agile principles of SCRUM to the dynamic and complex mining environment. In this model, each component of the extraction process, from mining trucks to drilling and loading equipment, becomes an active element of the SCRUM team. The cornerstone of this proposal is the introduction of a specialized Large Language Model (LLM), which acts as a SCRUM Master. This LLM, trained explicitly in mining operations through advanced fine-tuning techniques, coordinates and optimizes tasks in real time, constantly adapting to the deposit's changing conditions, variations in mineral quality, and operational priorities. The proposed system seeks to integrate data-driven decision-making with the flexibility of the agile approach. This synergy between artificial intelligence and SCRUM principles enables more dynamic planning, more efficient execution, and enhanced responsiveness to unforeseen challenges that are common in mining operations. The implementation of this methodology must comply with relevant international standards in the mining industry and project management, such as those established by the International Organization for Standardization (ISO) and the Institute of Electrical and Electronics Engineers (IEEE).

Compliance with these standards ensures that the framework is effective, efficient safe, sustainable, and compatible with global best practices. These practices include but are not limited to, ISO 14001 standards for environmental management, ISO 45001 for occupational health and safety, and IEEE standards for information technology and automation. Regarding the process and technologies involved (Figure 1), SCRUM elements are meticulously adapted to the mining context. A product backlog containing prioritized extraction and transportation tasks is implemented, while daily meetings are automated for efficient sprint planning. The LLM generates daily status reports and leads weekly evaluations and retrospective reviews, ensuring continuous process improvement. The technological infrastructure is crucial in this implementation, including an advanced digital task management system, a network of sensors and telemetry installed in mining equipment for real-time monitoring of critical parameters, and a sophisticated communication interface between the LLM and human operators. The workflow begins with a comprehensive review of the backlog by the LLM, followed by the precise allocation of tasks. Throughout the day, monitored execution of these tasks is carried out, with real-time adjustments as necessary, culminating in a detailed progress report at the end of the day. Particular emphasis is placed on rigorous training of operators in SCRUM principles and effective interaction with the LLM system to ensure the success of this integration. Additionally, a continuous adjustment process for the LLM model is implemented based on the analysis of historical data and ongoing feedback from the team, ensuring permanent system optimization and increasingly precise adaptation to the specific needs of the mining operation.

The critical actors in this adapted SCRUM model are:

Product Owner (PO):

- Role: Mining operations engineer.
- Responsibilities:
  - Define and prioritize production objectives.
  - Establish daily and weekly goals based on needs.
  - Balance production demands with mineral quality considerations and operational constraints.
  - Act as a liaison between mine management and the SCRUM team.

SCRUM Master (specialized LLM):

- Characteristics:
  - LLM with specific fine-tuning for mining operations.
  - Real-time processing capability of complex data.
- Functions:
  - Coordinate and optimize extraction and transportation tasks.
  - Facilitate communication between all team components.

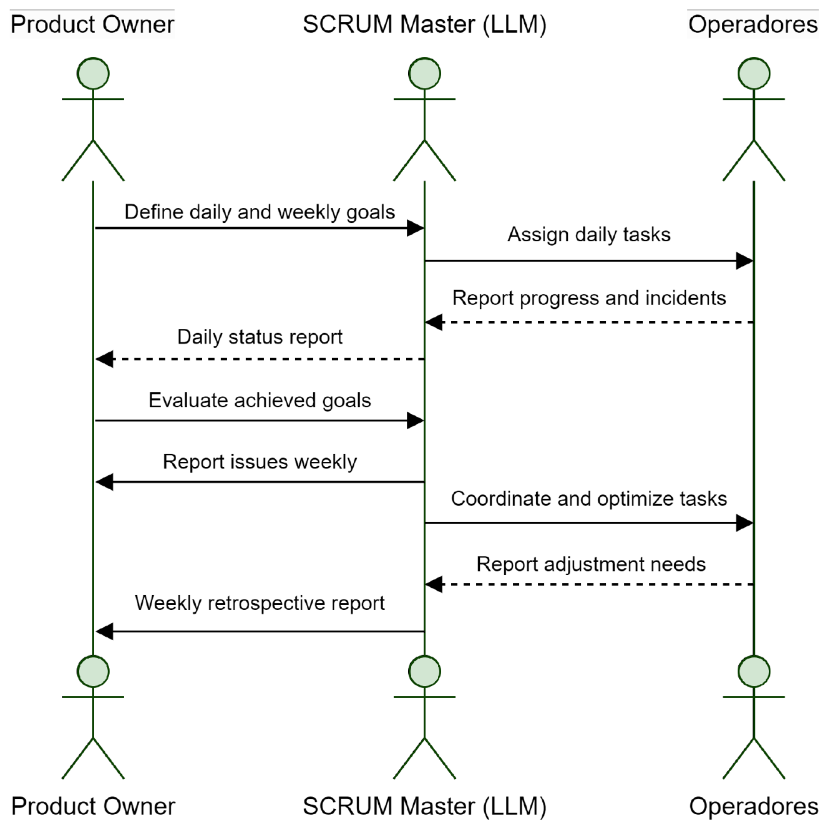

Figure 1. Solution Model - ScruMine.

- Identify and resolve operational impediments.
- Ensure adherence to SCRUM practices adapted to the mining context.
- Perform predictive analyses to anticipate problems and opportunities.

Development Team:

- Composition:
  - Mining trucks and their operators.
  - Drilling and blasting equipment.
  - Loaders and excavators with their respective operators.
  - Maintenance and support personnel.
- Responsibilities:
  - Execute tasks assigned by the SCRUM Master (LLM) and PO.
  - Provide continuous feedback on the status of operations.
  - Implement real-time improvements and adjustments as per LLM guidelines.
  - Collaborate in problem-solving and process optimization.

Support Systems:

- Components:
  - Sensors and telemetry systems in extraction equipment.
  - Global positioning systems and real-time mapping.
  - Communication interfaces between the LLM and operators.
  - A digital task management platform is integrated with mine control systems.
- Functions:
  - Collect and transmit real-time data on equipment status and deposit conditions.
  - Facilitate fluid communication between all SCRUM team components.
  - Provide visualizations and analytics for informed decision-making.

BENEFITS AND LIMITATIONS

The SCRUM methodology, adapted to mining extraction, can offer several benefits, including greater operational flexibility, improved efficiency in extraction processes, real-time optimization of data-driven decisions, and more effective communication between different components of the mining team. This approach enables for a faster response to changes in deposit conditions or production demands, potentially leading to increased productivity and a reduced downtime. Additionally, integrating an LLM as a SCRUM Master can provide advanced predictive analytics, improving both short-term and long-term planning.

However, the adoption of this methodology is not without its challenges. It necessitates a substantial investment in technology and training, which may be a barrier for some mining operations. There is also the potential for resistance to change from personnel who are accustomed to traditional methods. The reliance on advanced technological systems introduces vulnerabilities to technical failures or cyberattacks. Furthermore, adapting SCRUM to the complex and physically demanding environment of mining may face practical obstacles, and the effectiveness of the LLM as SCRUM Master will largely depend on the quality of its training and the accuracy of the data it receives.

CONCLUSIONS

The mining industry is a sector that continually innovates and evolves. This evolution is driven by the need to improve efficiency, reduce costs, and meet growing environmental and sustainability demands. Integrating artificial intelligence in the mining industry transforms the way mineral resources are explored, extracted, and processed, necessitating more efficient and effective management. In this context, this article presents ScruMine, an innovative approach that integrates the SCRUM methodology with advanced artificial intelligence technologies to optimize extraction processes in the mining industry. The proposal adapts agile principles to the complex and dynamic environment of mining operations, introducing a Large Language Model (LLM) as SCRUM Master and redefining traditional roles within the extraction team. ScruMine aims to enhance operational flexibility, improve efficiency in extraction processes, and facilitate real-time data-driven decision-making. However, it is essential to recognize that implementing this approach involves significant challenges. The substantial investment in technology and training, possible resistance to change from personnel, and dependence on advanced technological systems are obstacles that must be carefully considered and addressed. The actual effectiveness of ScruMine in the mining context is yet to be demonstrated. Adapting SCRUM to a physically demanding and complex environment, such as mining, may face practical obstacles that require continuous adjustments and refinements. As future work, it is planned to develop and test this methodology using Autodesk's FlexSim simulator. This simulation phase will be crucial for assessing the viability and effectiveness of the proposed framework in various mining extraction scenarios, allowing for adjustments and optimizations before implementation in natural environments. The results of these simulations will provide valuable insights for developing and refining the ScruMine framework.

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REFERENCES

[1] R. Ranosz, "Mining and its role in the global economy," Gospodarka Surowcami Mineralnymi, *Mineral Resources Management*, vol. 30, no. 1, 2014, doi: 10.2478/gospo-2014-0003.

[2] I. Dorin, C. Diaconescu, and D.I. Topor, "The Role of Mining in National Economies," *International Journal of Academic Research in Accounting, Finance and Management Sciences*, vol. 4, no. 3, pp. 211-218, Jul. 2014, doi: 10.6007/IJARAFMS/v4-i3/1116.

[3] D.A. Escalante Yaulilĩaca, Y.C. Jeri Huamaco, R.M. Apolinario Torres, R.R. Roque Durand, and P.R. Venegas Rodríguez, "Un estudio de la competitividad exportadora de los principales productos mineros peruanos (2010-2019),"

Revista de Métodos Cuantitativos para la Economía y la Empresa, vol. 33, pp. 264-284, Jun. 2022. [Online]. Available https://www.econstor.eu/handle/10419/286271

[4] A. Kitsanu and S.S. Saxey, "Global mining in the 21st century: An overview" *Journal of Geography and Cartography*, vol. 7, no. 1. Art. no. 6090, Jun. 2024, doi: 10.24294/jgc.v7i1.6090.

[5] N.R. Banerjee, L.I. Van Loon, T.J. Flynn, and D. Muir, "Development of rapid synchrotron 2D X-ray Mapping and XANES of rock slabs and drill core as a tool for the mineral exploration and mining industries," *Microscopy and Microanalysis*, vol. 24, no. S2, pp. 510-511, Aug. 2018, doi: 10.1017/S1431927618014770.

[6] C. Castanetto and B. Servetto, "Past, Present and Future of Copper Mine Tailings Governance in Chile (1905-2022): A Review in One of the Leading Mining Countries in the World," *International Journal of Environmental Research and Public Health*, vol. 19, no. 20, Art. no. 2022, doi: 10.3390/ijerph192013060.

[7] COCHILCO, "Observatorio de Costos de la Gran Minería del Cobre año 2023," cochilco.cl. [Online]. Available: https://www.cochilco.cl/web/observatorio-de-costos-de-la-gran-mineria-del-cobre-ano-2023

[8] Oxford Analytica "Lithium deal aims to avoid missed opportunity in Chile," *Expert Briefings*, 2024, doi: 10.1108/OXAN-DB284549.

[9] M.N. Herrera, "The contribution of the Chilean mining industry to the achievement of the 17 sustainable development goals," *Geosystem Engineering*, vol. 25, no. 3-4, pp. 64-82, 2022, doi: 10.1080/12269328.2022.2147588.

[10] B. Wang, B. Gong, W. Xu, and X. Shi, "An efficient method for modeling and evaluating the bench terrain of open-pit mines," *Frontiers in Earth Science*, vol. 12, Art. no. 1351352, May 2024, doi: 10.3389/feart.2024.1351352.

[11] S. Esmaielzadeh, E. Bakhtavar, M. Mokhtarian-Asl, R. Sadiq, and K. Hewage, "Mathematical modelling of waste rock management through integrating open-pit waste rocks in underground stope filling: An environmental approach," *Resources Policy*, vol. 85, Art. no. 103085, 2023, doi: 10.1016/j.resourpol.2023.103885.

[12] O. Aş'd and M. Levesque, "Digital technologies for energy efficiency and decarbonisation in mining," *CIM Journal*, vol. 15, no. 1, pp. 1-20, 2024, doi: 10.1080/19236026.2023.2203068.

[13] A. Hammond, B. Donnelly, and N. Ashwath, Eds. *Mining Technology*, London, UK: IntechOpen, 2022, doi: 10.5772/intechopen.95642.

[14] Z. Hyder, K. Siau, and F. Nah, "Artificial intelligence, machine learning, and autonomous technologies in mining industry," *Journal of Database Management*, vol. 30, no. 2, pp. 67-79, 2019, doi: 10.4018/jdm.2019040104.

[15] S. Zhironkin and D. Surguz, "Mining technologies innovative development: Industrial, environmental and economic perspectives," *Energies,* vol. 15, no. 5, Art. no. 1756, 2022, doi: 10.3390/en15051756.

[16] S. Zhironkin and D. Szurgacz, "Mining technologies innovative development: Economic and sustainable outlook," *Energies,* vol. 14, no. 24, Art. no. 8590, 2021, doi: 10.3390/en14248590.

[17] C. Prasad Verma and A.K. Soni, "Stability of crown pillar during transition from open pit to underground mining," in *Technologies in Mining*, D.A. Soni, Ed. London, UK: IntechOpen, 2024, ch. 4, pp. 89-102, doi: 10.5772/intechopen.1004904.

[18] F. Sánchez and P. Hartlieb, "Innovation in the mining industry: Technological trends and a case study of the challenges of disruptive innovation," *Mining, Metallurgy & Exploration*, vol. 37, no. 5, pp. 1385-1399, Oct. 2020, doi: 10.1007/s42461-020-00262-1.

[19] M.C. Srivastava and B. P. Kamath, "Enhancing technologies to improve metallurgical processes,"in *Proceedings of the International Conference on Metallurgical Engineering and Materials Evaluationand and Centenary Celebration*, S. Patra, S. Sinha, G.S. Mahobia, and D. Kamble, Eds. Singapore: Springer Nature Singapore, pp. 347-357,2024, doi: 10.1007/978-981-99-6863-3_34.

[20] T.N. Matveeva, V.V. Getman, N.K. Gromova, and A.Y. Karkeshkina, "Contemporary research and developments in the low-toxic chelating reagents for the extraction of non-ferrous and noble metals from poor polymetallic ores and processing

tailings," *Sustainability,* vol. 14, no. 23, Art. no. 16262,2022, doi: 10.3390/su142316262.

[21] A. Novák, E. Fesenčo, and Y. Pavlov, "Improvement of technological processes for mining solid mineral resources," *Technology Audit and Production Reserves*, vol. 5, no. 1(61), pp. 41-45, Oct. 2021, doi: 10.15587/2706-5448.2021.240260.

[22] W. Su, T. University, S. Xu, and F. Liu, "Design of collaborative computing and mining truck autonomous driving system based on AUTOSAR Adaptive Platform," in *2022 International Conference on Computer Engineering and Artificial Intelligence (ICCEAI),* Shijiazhuang, China, 2022, pp. 618-622, doi: 10.1109/ICCEAI55464.2022.00131.

[23] X. Ma, E. Huo, H. Yu, and H. Li, "Mining truck platooning patterns through massive trajectory data," *Knowledge-Based Systems*, vol. 221, Art. no. 106972, 2021, doi: 10.1016/j.knosys.2021.106972.

[24] F. Cuevas, C. Murray, W. Platzer, and A. Heimsath, "Large scale solar plants integration in electro-winning copper recuperation process," *Energy Procedia*, vol. 70, pp. 605-614, 2015, doi: 10.1016/j.egypro.2015.02.167.

[25] B.K. Kenzhaliyev, S.A. Kvyatkovskiy, S.A Trebukhov, R.A. Abdulvaliyev, A.K. Koizhanova, N.K. Tussupbayev, S.V. Gladyshev, and G.K. Kassymova, "Development and implementation of innovative technologies that ensure an increase in the extraction of non-ferrous, noble, rare, rare-earth metals," *Feknomekanik*, vol. 5, no. 1, pp. 1-12, Jan. 2022, doi: 10.24036/teknomekanik.v5i1.11972.

[26] G. Yadagir, M. Sudha, V.S. Reddy, G.D. Rani, S. Sophia, and J.F. Roseline, "Artificial neural network and implementation of robotic arm for mineral extraction in mines with permanent magnet synchronous motor," in *2023 International Conference on Inventive Computation Technologies (ICICT),* Lalitpur, Nepal, 2023, pp. 385-390, doi: 10.1109/ICICT57646.2023.10134219.

[27] Y. Fang and X. Peng, "Micro-factors-aware scheduling of multiple autonomous trucks in open-pit mining via enhanced metaheuristics," *Electronics,* vol. 12, no. 18, Art. no. 3793, 2023, doi: 10.3390/electronics12183793.

[28] X. Zhang, A. Guo, Y. Li, B. Peng, and Y. Chen, "Real-time scheduling of autonomous mining trucks via flow allocation-accelerated tabu search," *IEEE Transactions on Intelligent Vehicles*, vol. 7, no. 3, pp. 466-479, 2022, doi: 10.1109/TIV.2022.3166564.

[29] M. Zhou, Y. Wang, R. Zhang, Z. Li, Y. Luo, and X. Liu, "Lidar odometry for autonomous mining trucks utilizing massif registration," in *2023 IEEE International Conference on Unmanned Systems (ICUS),* Hefei, China, 2023, pp. 1-6, doi: 10.1109/ICUS58632.2023.10318505.

[30] P. Spagnoletti, N. Kazemargi, and A. Prencipe, "Agile practices and organizational agility in software ecosystems," *IEEE Transactions on Engineering Management,* vol. 69, no. 6, pp. 3604-3617, 2022, doi: 10.1109/TEM.2021.3110105.

[31] F.S. Karal and A. Soyer, "The impact of digital enterprise transformation strategies on project managers' competencies," *Handbook of Research on Management and Strategies for Digital Enterprise Transformation*, K. Sandhu, Ed. New York, USA: IGI Global, 2020, pp. 274-287. [Online]. Available: https://www.igi-global.com/chapter/the-impact-of-digital-enterprise-transformation-strategies-on-project-managers-competencies/273790

[32] P. Eylund, J. Mehta, N. Mathavan, K. Trowbridge, B. Taylor, H. El Shami, and N. Campbell, "Using agile methodology and design strategies to improve enrollment in clinical trials," *Innovation in Aging*, vol. 6, no. S1, p. 652, Dec. 2022, doi: 10.1093/geroni/igac059.2409.

[33] T. Broda *et al.*, "The agile working method for legal departments," *Jusletter IT*, no. 20, 2022, doi: 10.38023/fc0c658d-1230-45ca-bf08-bf3113e2d678.

[34] M. Termazia and C. Sarzosa, "Agile methodologies in the fashion industry," in *Proceedings of the 5th International Conference on Intelligent Human Systems Integration (IHSI 2022)*, Integrating People and Intelligent Systems, vol. 22, 2022, doi: 10.54941/ahfe1001050.

[35] T. Gustavsson, M. Berntzen, and V. Stray, "Changes to team autonomy in large-scale software development: A multiple case study of Scaled Agile Framework

(SAFe) implementations," *International Journal of Information Systems and Project Management*, vol. 10, no. 1, pp. 29-46, Apr. 2022. [Online]. Available: https://aisel.aisnet.org/ijispm/vol10/iss1/3

[36] NTTData, "Agilidad en Latinoamérica 2024," ec.nttdata.com. [Online]. Available: https://ec.nttdata.com/insights/studies/agilidad-2024

[37] B.A. Wills and J.A. Finch, *Wills' Mineral Processing Technology: An Introduction to the Practical Aspects of Ore Treatment and Mineral Recovery*, 8th ed. Oxford, UK: Elsevier, 2016. [Online]. Available: https://www.sciencedirect.com/book/9780080970530/wills-mineral-processing-technology.

[38] J.H. Ccatamayo-Barrios *et al.*, "Comparative analysis of AHP and TOPSIS multi-criteria decision-making methods for mining method selection," *Mathematical Modelling and Engineering Problems,* vol. 10, no. 5, pp. 1665-1674, Oct. 2023, doi: 10.18280/mmep.100516.

[39] E. Cetin and A. Dalgic, "Optimization of cut-off grades and depletion rates by means of dynamic programming," *Eximia*, vol. 13, no. 1, pp. 526-539, Jun. 2023, doi: 10.47577/eximia.v13i1.483.