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A VDC FRAMEWORK PROPOSAL FOR TIME OPTIMIZATION IN DIAMOND DRILLING OPERATIONS FOR MINING

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ABSTRACT

A Virtual Design and Construction (VDC) framework proposal is presented for time optimization in diamond drilling operations for a mining exploration project. The mining project is located in the Huancavelica region of Peru and is currently in the underground exploration phase through diamond drilling drillholes. The geology team uses diamond drilling samples to estimate the total mineral reserves of the mine, and they have projected 13,278 meters to be drilled. The VDC framework proposal's application allowed a better understanding of diamond drilling processes to support the variability source reduction related to equipment, maintenance and operational tasks. The results showed a time optimization in the diamond drilling operation of 10%.

KEYWORDS

VDC, diamond drilling, mining explorations, project management, process optimization.

INTRODUCTION

Mining exploration projects focus on generating new prospects and exploring them to locate and define the ore bodies that lie in them (Marjoribanks, 2010). The present investigation was conducted in a mining project's exploratory phase located in the department of the Huancavelica region of Peru by diamond drilling. This exploratory project aims to estimate ore reserves by exploring identified veins. The diamond drilling exploration consists of drilling holes previously identified and approved by the geology department with a specified depth angle and azimuth. For this project, the drilling depths were an average of 300m long. The geologists first analyze the cylindrical-shaped rock samples collected from the drilling process and then send them to a laboratory for further investigation. According to Uvarova et al. (2015), this exploration campaign is summarized in drilling, collecting, logging, and cutting diamond cores for laboratories that will analyze them.

For the exploratory activities of the project, a company specialized in diamond drilling was commissioned. They had two drilling machines of similar size and capacity during most of the project and worked in conjunction with the exploration department of the mining company. This department was responsible for indicating the points to be drilled and preparing the samples for subsequent shipment to the chosen laboratory.

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The drilling company's operations started in April 2022, and several drilling samples were obtained during the first 5 months of work. However, the recovered cores' quality was below the exploration department's standards. It was observed that the drilling speed was higher than usual, resulting in defective samples. This situation obligated the company to issue an order to the drilling company to slow down the speed, reducing the number of cores but increasing the core quality. This order changed the expected production from 20% to only 0.05% over the monthly target, as shown in Figure 1.

The objective of the exploration campaign of the mining company was to use the cores obtained between the start of the exploration on April 18, 2022, until October 31, 2022, for reserves estimation. There was no established metric for the number of cores to be obtained at the end of the established period. However, considering the minimum goals agreed upon with the drilling company, 1,100 meters per machine per month, this period should be completed with at least 13,278.06 meters of diamond cores. Due to the drilling speed reduction, the target value of 1,100 meters per month was barely reached, resulting in 1,453.01 meters being executed in the remaining two months.

The literature review revealed several studies on productivity optimization in exploratory mining projects and diamond drilling operations, but these studies differed considerably. For instance, Boeksr (1930) proposed a new design of a diamond drilling machine capable of reaching greater depths and speeds. In contrast, Gao (2021) focused on optimizing time through a new method of performing depth measurements of diamond drill holes. Another study by Mustafa et al. (2021) investigated optimizing productivity by controlling drilling parameters to increase drilling speeds.

To not affect the estimation of mineral reserves, which depend on the exploratory campaigns, a VDC framework was developed focused on increasing productivity and complying with the standards of the exploration department.

Virtual Design and Construction (VDC) is a methodology created by the Center for Integrated Facility Engineering (CIFE) at Stanford University in 2001. According to Del Savio et al. (2022) and Rischmoller et al. (2018), VDC refers to utilizing multidisciplinary performance models in design and construction projects. VDC is composed of: Client Objectives, Project Objectives, Production Objectives (Production Metrics), Controllable Factors, Integrated Concurrent Engineering (ICE), Building Information Modeling (BIM), and Project Production Management (PPM) (Del Savio et al., 2022). The VDC components are summarized in a framework called VDC Framework, which integrates them and enables better management for developing a project. By fulfilling their controllable factors and production objectives, the PPM, ICE, and BIM components seek the success of the project's objectives, which, consequently, also achieve the client's objectives since they are directly linked to each other. According to Rischmoller et al. (2018), process (PPM), organizational (ICE), and information (BIM) knowledge must be integrated to produce the highly integrated systems necessary for a high-performance project.

The literature review shows limited examples of the VDC methodology implementation in mining projects, mainly because its application has been initially focused on the construction industry. Del Savio et al. (2022), who complied 7 case studies of the VDC application, showed that this methodology achieves optimization of costs, time, resources, and quality of the projects, which is why it was decided to apply and demonstrate its potential use and advantages in the mining industry.

This research seeks to demonstrate the efficacy of the VDC methodology as a viable alternative for overseeing mining exploration initiatives that involve diamond drilling. By implementing the VDC methodology, this study aims to highlight how it can optimize the exploration process, improve the quality of collected data, and ultimately lead to better decision-making in the mining industry.

METHODOLOGY

The methodology used for the research development includes collecting data from one of the project's drilling rigs during the first 5 months of operations from a 7-month project. It was collected from the daily reports sent by the contractor and entered into a database made for the exploration progress on an Excel file. The data collected corresponds to the physical progress, the detailed use of working hours for each shift, and the work processes used. With the information collected, it was identified the main sources of variability that generated a lower number of drilling hours. The methodology consisted of developing the VDC framework, defining its components, establishing the new processes with PPM, and identifying the variability sources. The corresponding results were obtained for each component of the VDC Framework.

DATA OBTAINED

The project worked with two drilling rigs during most of the project. Drilling rigs DE-130 and H-200 models were used, being the H-200 model replaced by a DE-140 model on August 21, 2022. The DE-130 drilling rig, which worked from the beginning of the project on April 18, was withdrawn on October 12, 2022, leaving only the DE-140 drilling rig until the end. Due to these circumstances, the data collected that served for the VDC implementation was from the DE-130 drilling rig, which has complete data for the 5 months before the order to decrease the drilling speed, and it is with the work of the DE-140 drilling rig that the VDC methodology was implemented. The drilling rig changes caused a week's loss in which the project lost at least 300m of samples considering the average daily drilling.

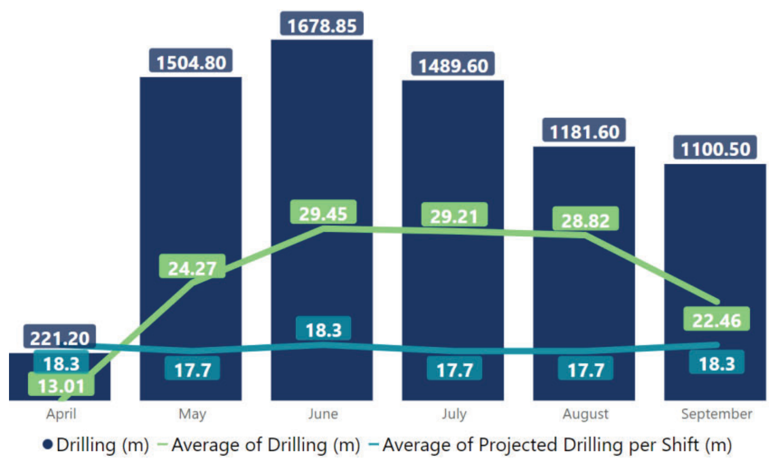

Figure 1: Monthly and daily drilling performance for the DE-130 drilling rig

As shown in Figure 1, the DE-130 rig performed well, surpassing its monthly drilling target of 1,100 meters by 24.59% (except for April 2022, when it started operations). It maintained an average throughput of 26.65 meters/shift during high-speed drilling months but decreased to 22.46 meters/shift (down 16%) in September 2022, slightly exceeding the monthly target by 0.05%.

Two main variability sources were identified, working in collaboration with the DE-140 team (Figure 2): those attributed to the drilling and mining companies. These variability sources were identified through the processing of data and the creation of statistical graphs, as shown in Figure 3. The lost hours were classified by type and then shown on graphs, allowing their better understanding and effect on the project.

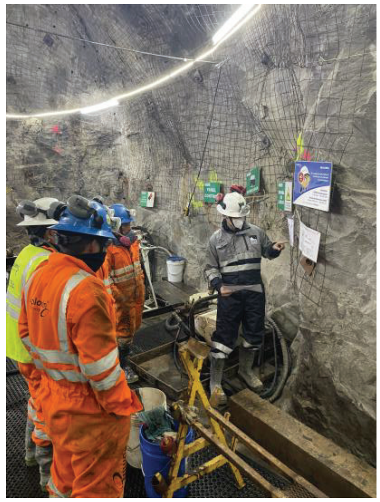

Figure 2: Introducing the DE-140 team to VDC.

Among the sources of variability attributable to the drilling company shown in Figure 3, corrective maintenance (maintenance caused by malfunctions of the drilling rig) and operational delays (delays caused by the drilling team's operations) stand out, accounting for 10.31% and 10.00% of the drilling hours executed.

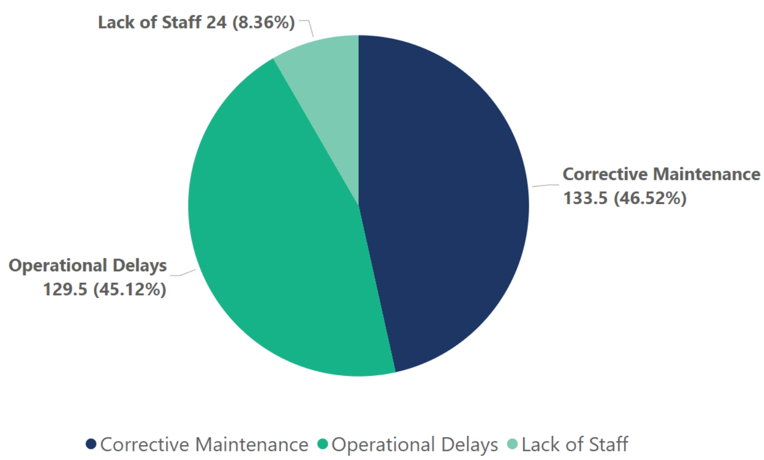

Figure 3: Variability sources attributable to the drilling company

The sources of variability attributable to the mining company correspond to the standby times that are the company's responsibility. The three sources of variability identified and shown in Figure 4, corresponding to standby, total 82.5h and are equivalent to 6.38% of the drilling hours.

The process flow shown in Figure 5 was obtained by observing the joint work of the mining and drilling companies and by interviews with the key stakeholders, such as the operations chief and mine superintendent. A considerably basic process flow is evident in which there is no differentiation by area involved or integration between them. The process consisted of the morning and night meetings before the beginning of each shift, finishing with the sending of the daily report before the next day's morning meeting.

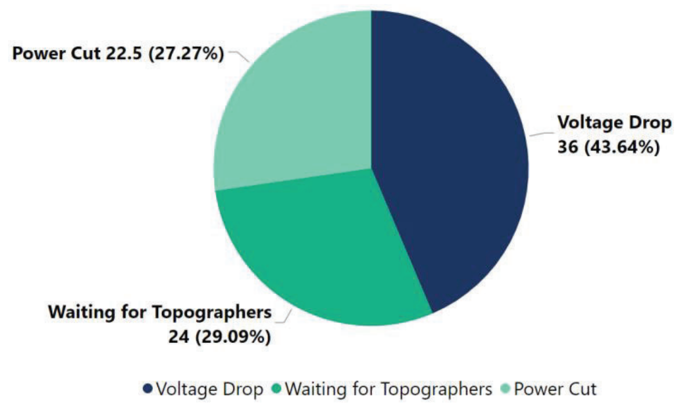

Figure 4: Sources of variability attributable to the mining company

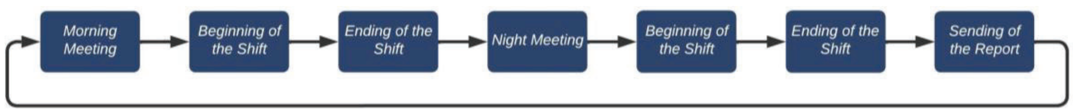

Figure 5: Work process before VDC

PROPOSAL APPROACH

The work proposal for implementing VDC in the project should focus on meeting the client's objective of 13,278.06 meters of drilled cores to estimate reserves. Next, the project's objective was defined. Focused on implementing time optimization by mitigating sources of variability to increase production to 14,606.87 meters of core drilled, which is 10% more than the client's objective. Once the implementation objectives were defined, the PPM, ICE, and BIM components were designed.

The PPM component, focused on the processes and operation, has as a production objective the reduction of variability sources to less than 10% of drilling hours and, as a controllable factor, the review of improvement proposals obtained in the ICE sessions. The ICE component, focused on the organization, has as a production objective the resolution of 100% of the improvement proposals by the stakeholders received during its sessions and the number of ICE sessions performed per day as a controllable factor. Finally, the BIM component, focused on information integration, was implemented through control dashboards that were connected to an Excel database, where PPM production objectives are displayed in an interactive and easy-to-understand manner so that all team members could see updated project information and make decisions not only in the ICE sessions but also in the field. It had as a production objective the time to receive drilling reports, which should be <=15 minutes from the departure of the drilling rig from the mine, and as a controllable factor, the number of dashboard updates per day. The BIM production objective is due to the time it takes to send the daily reports since they were only used to record the progress and calculate the valuations. Both reports were sent together once a day, which caused a delay in the reception and processing of the information.

RESULTS AND DISCUSSIONS

IMPLEMENTATION OF PROPOSAL

The VDC implementation approach is translated into the VDC Framework, which groups the VDC components in a graphical and interrelated way to fulfill their integration. In addition, it includes explicit specifications of customer and project objectives, performance measurement, and project models (Kunz & Fischer, 2020), as seen in Figure 6.

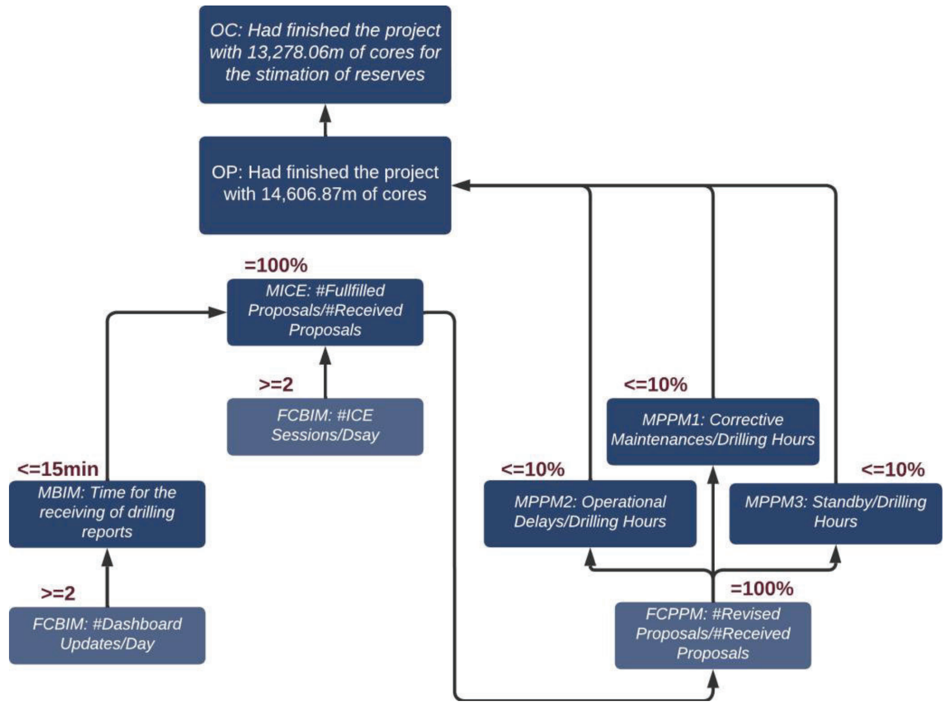

Figure 6: VDC Framework

The VDC Framework allows optimal visualization of the methodology and its implementation. Likewise, the process flow between the different areas shown in Figure 5 had to be updated according to the new needs demanded by the proposed VDC implementation, as shown in Figure 7.

According to the VDC Framework, the updated process flow integrates the different areas, focusing on productivity by sharing information and reducing query response latency, enabling decision-making before and during operations.

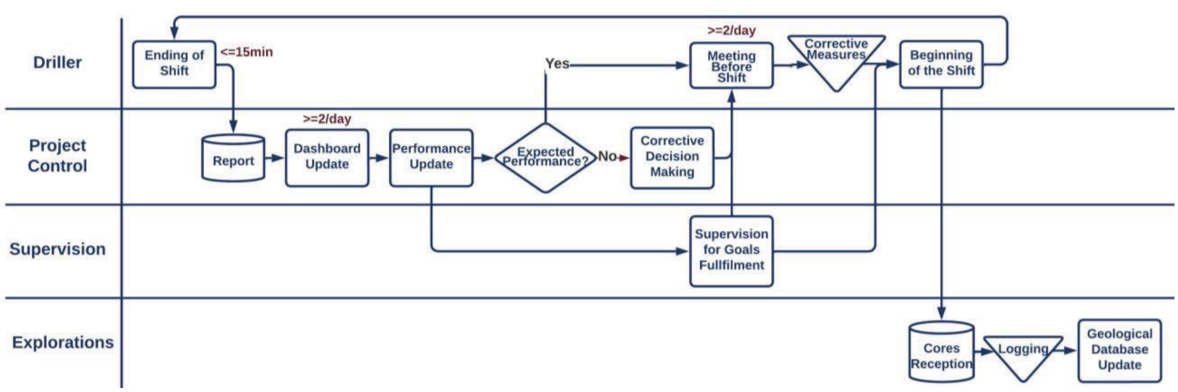

Figure 7: Work Process with VDC

Proposal Validation

The project specialists validated the proposal: the exploration director, general superintendent, project superintendent of the mining company, and the operations manager of the drilling company. Each one of the project specialists was interviewed to obtain their feedback.

VDC Objectives

The specialists stressed the importance of complying with the exploration department's decision and preventing the drilling team from focusing only on the meters drilled. This could lead them to increase the drilling speed to meet a physical progress goal.

PPM

The experts agreed that increasing production by mitigating the previously identified sources of variability was a viable alternative for meeting the objective.

ICE

The specialists agreed and supported disseminating the ICE sessions held during the on-call sessions. Previously, the agenda of these sessions was the distribution of information on the work to be performed during the on-call period. With the implementation of the ICE sessions, information began to be shared with all involved, and decisions began to be made during the sessions. The main topics of these sessions were the measures to be implemented to lower the variability shown on the dashboards from the VDC component.

BIM

Before starting the VDC implementation, the stakeholders witnessed the initial development of the dashboards, as shown in Figure 8. They showed interest in them, even requesting their distribution to know the project's status. Once implemented, they were aligned with the current information integration system.

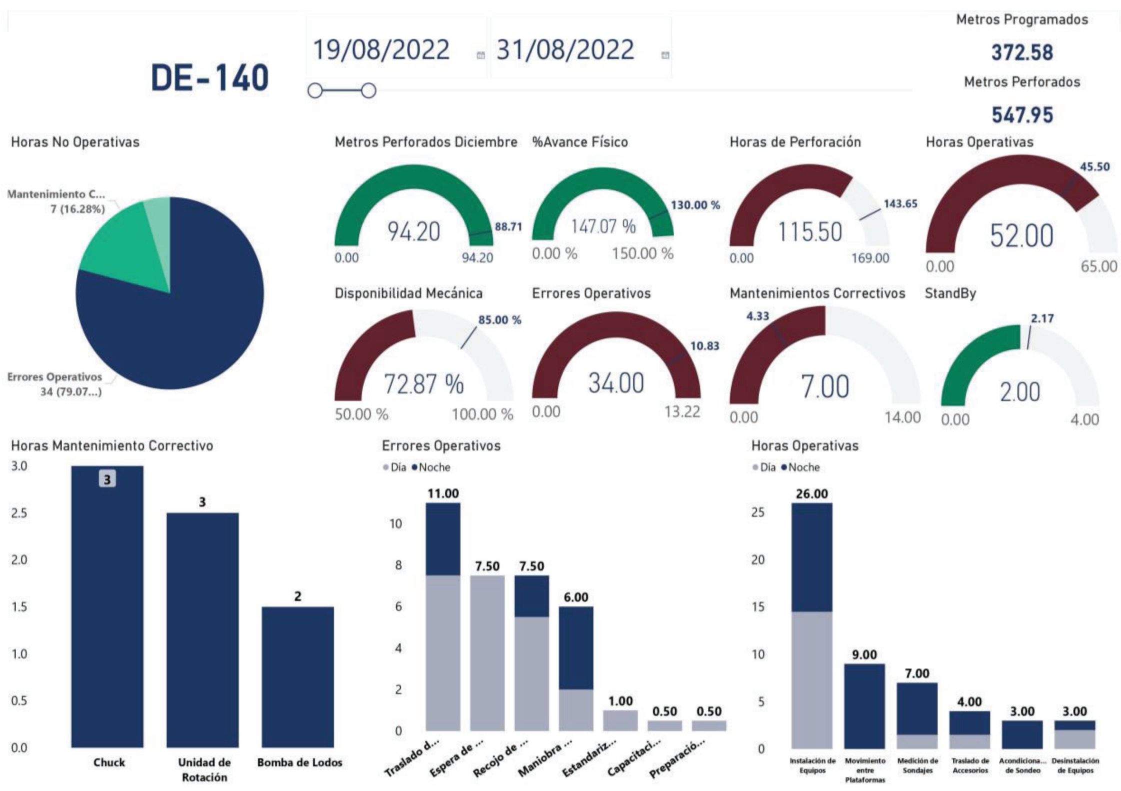

Figure 8: The dashboard for the integration of information

Client's Objective

The client's target of completing the project with 13,278.06 meters of core was surpassed, finishing the project with 15,794.20 meters drilled, which is 18.95% above the target.

Project's Objective
The project's target of 14.606.87 meters of core drilled was also surpassed by 8.13% above the target.

PPM, ICE and BIM
The results of the PPM, ICE, and BIM production objectives are shown in Table 1.

Table 1: PPM, ICE and BIM production objectives

Components	Production Objectives	Objective	Result
PPM	$\frac{Corrective\ Maintenances\ Hours}{Drilling\ Hours} x100\%$	<=10%	9.61%
	$\frac{Operational\ Delays\ Hours}{Drilling\ Hours} x100\%$	<=10%	18.31 %
	$\frac{StandBy\ Hours}{Driling\ Hours} x100\%$	<=10%	9.03%
BIM	Time for the receiving of drilling reports	<=15min	9 min
ICE	$\frac{\#Fullfilled\ Proposals}{\#Received\ Proposals} x100\%$	=100%	100%

As shown in Figure 9, the DE-140 drilling rig drilled 2,349.35 meters, exceeding the goal by 6.79% the 2,200.00 meters goal and abiding by the explorations department's order, while the DE-130 drilling rig only exceeded its monthly goal by 0.05% (Figure 10). Both DE-140 and DE-130 drilling rigs worked simultaneously during September 2022.

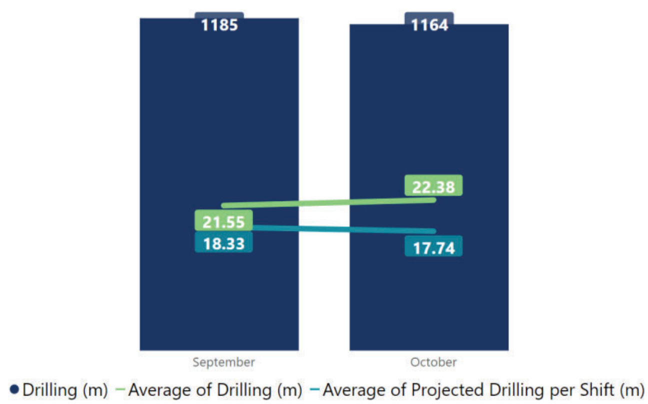

Figure 9: DE-140 drilling rig performance

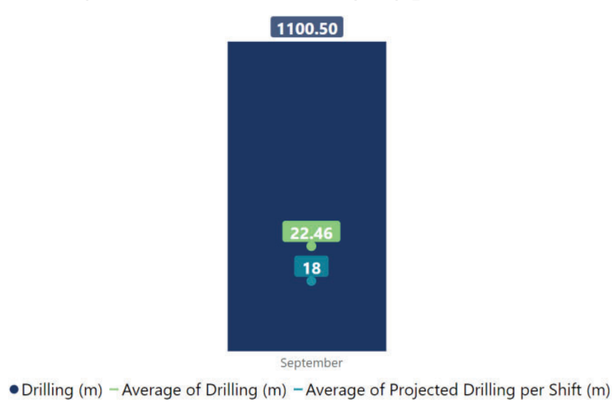

Figure 10: DE-130 Drilling rig performance in September

VDC implementation on this project focused on time optimization. With the identification of each variability source, the project stakeholder discussed and proposed improvement measures during ICE sessions to reduce those sources of variability. Some of the proposals received during ICE sessions were related to integrating stakeholders, and some were related to increasing staff. Considering that some proposals demanded an increasing budget, they had to be revised and analyzed.

CONCLUSIONS

The VDC implementation helped surpass the client's and project objectives as well as the ICE, BIM and PPM objectives except for the operational delays vs. drilling hours one. Although the drilling campaign was projected to be completed above the minimum target due to the performance in the first 5 months, the DE-140 drill rig, which was the subject of the investigation, managed to exceed its target by 6.79% for September and October 2022. The main difference in conditions between the two machines is the number of drilling hours achieved, with the DE-140 machine having a total of 319 hours of drilling and the DE-130 machine a total of 260 hours, equivalent to a 23% difference between both machines, which allowed that, despite the presence of the sources of variability, the DE-140 drilling machine achieved a higher production since its sources of variability were identified and controlled.

It can be concluded that the implementation of the VDC methodology was successful, with the DE-140 drill rig having shown higher production compared to a similar rig under the same conditions. In addition, compliance with the VDC production objectives indicates adequate project progress toward the client's and project objectives.

Finally, further investigation could be carried out considering the automation of entering information into the database and digitalizing the drilling reports.

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REFERENCES

Andersen, M. T., & Findsen, A. L. (2019). Exploring the benefits of structured information using virtual design and construction principles in a BIM life-cycle approach. Architectural Engineering and Design Management, 15(2), 83–100. https://doi.org/10.1080/17452007.2018.1546165

Andersson, L., Farrell, K., Moshkovich, O. & Cranbourne, C. (2016). Implementing Virtual Design and Construction using BIM: Current and future practices. https://doi.org/10.4324/9781315657073

Aslam, M., Gao, Z., & Smith, G. (2021). Integrated implementation of Virtual Design and Construction (VDC) and lean project delivery system (LPDS). Journal of Building Engineering. Elsevier Ltd. https://doi.org/10.1016/j.jobe.2021.102252

Boeksr, V.W. (1930). CONSTRUCTION AND OPERATION OF A SPECIAL DIAMOND CORE DRILL FOR EXPLORING SHALE DEPOSITS1. Journal of The American Ceramic

Society - J AMER CERAM SOC. 13. 145–149. https://doi.org/10.1111/j.1151-2916.1930.tb16267.x

Breit, M., Vogel, M., Häubi, F., Märki, F., Soldati, M., Etesi, L., Hochmuth, N. & Walther, A. (2023). Enhancement of Virtual Design and Construction Methods. Retrieved from: https://www.researchgate.net/publication/228697093_Enhancement_of_Virtual_Design_and_Construction_Methods

Dadykn, V., Dadykina, O & Elyakova, I. (2022). Project Management System of Exploration Program in the Light of Prioritizing of Reservoir Engineering Stages According to the Criterion of Prospects. IOP Conference Series: Earth and Environmental Science. https://doi.org/10.1088/1755-1315/988/2/022002

De Geoffroy, J.G. & Wignall, T.K. (1985). Designing Optimal Strategies for Mineral Exploration. Retrieved from: https://cloudflare-ipfs.com/ipfs/bafykbzacec5lunrnjv7visca26skuoto3nhkjdkondjh2kvmygcyrdwzf2f4y?filename=J.%20G.%20De%20Geoffroy%2C%20T.%20K.%20Wignall%20%28auth.%29%20-%20Designing%20Optimal%20Strategies%20for%20Mineral%20Exploration-Springer%20US%20%281985%29.pdf

Del Savio, A., Vidal, J., Bazán, A., Rischmoller, L. & Fischer, M. (2022). Virtual Design and Construction (VDC) Framework: A Current Review, Update and Discussion. Applied Sciences. https://doi.org/10.3390/app122312178

De St. Jorre, M.G.P. (1970). A Probabilistic Method of Ranking Underground Exploration Proposals [Master Thesis, Colorado School of Mines]. Retrieved from: https://repository.mines.edu/bitstream/handle/11124/175678/DeStJorre_10781683.pdf?sequence=1&isAllowed=y

Gao, J. (2021). Research on Drilling Depth Measurement Technology based on Drilling Rig Parameter Monitoring. Journal of Physics: Conference Series. 2029. 012139. http://doi.org/10.1088/1742-6596/2029/1/012139

Hassan, H., Taib, N. & Rahman, Z. (2018). Virtual Design and Construction: a new communication in construction industry. ICDSP 2018: Proceedings of the 2nd International Conference on Digital Signal Processing. 110-113. http://doi.org/10.1145/3193025.3193062

Koutamanis, A. (2017). Briefing and Building Information Modelling: Potential for integration. International Journal of Architectural Computing, 15(2), 119–133. Retrieved from: https://doi.org/10.1177/1478077117714914

Kunz, J & Fischer, M. (2020). Virtual design and construction. Construction Management and Economics. 38. 1-9. http://doi.org/10.1080/01446193.2020.1714068

Logn, Ø. (1964). Problems in underground deep diamond drilling. Geoexploration. 2. 107–121. http://doi.org/10.1016/0016-7142(64)90003-1

Marjoribanks, R. (2010). Geological Methods in Mineral Exploration and Mining. http://doi.org/10.1007/978-3-540-74375-0

Mustafa, A., Abbas, A., Alsaba, M. & Alameen, M. (2021). Improving drilling performance through optimizing controllable drilling parameters. In Journal of Petroleum Exploration and Production (2021) 11:1223–1232. https://doi.org/10.1007/s13202-021-01116-2

Quiso, E., Rivera, J., & Farje, J. (2021). Proposal for the application of ICE and BIM sessions to increase productivity in construction. In Journal of Physics: Conference Series (Vol. 1803). IOP Publishing Ltd. Retrieved from: https://doi.org/10.1088/1742-6596/1803/1/012027

Rischmoller, L., Reed, D., Khanzode, A., & Fischer, M. (2018). Integration enabled by virtual design & construction as a lean implementation strategy. In IGLC 2018 - Proceedings of the 26th Annual Conference of the International Group for Lean Construction: Evolving Lean Construction Towards Mature Production Management Across Cultures and Frontiers (Vol.

1, pp. 240–249). The International Group for Lean Construction. https://doi.org/10.24928/2018/0521

Shenoy, R. (2017). A Comparison of Lean Construction with Project Production Management. Project Production Institute. Retrieved from: https://projectproduction.org/wp-content/uploads/2017/09/PPI-JOURNAL-PPIPP-A-Comparison-of-Lean-Construction-with-Project-Production-Management.pdf

Stefaniak, P.K., Wodecki, J., Zimroz, R., Sliwinski, P. & Andrzejewski, M. (2016). The multivariate analysis of monitoring system data from mining drilling machine. Retrieved from: https://www.researchgate.net/publication/304999247_The_multivariate_analysis_of_monitoring_system_data_from_mining_drilling_machine

Takodjou, J. & Tanni, W. (2022). GIS and Database Management for Mining Exploration. http://doi.org/10.5772/intechopen.106632

Tichauer, R., Abreu, G. & De Tomi, G. (2021). Method of Comparable Values: A New Approach for Efficient Exploration Target Selection in Small-Scale Mining. Natural Resources Research. 30. http://doi.org/10.1007/s11053-021-09855-z

Uvarova, Y., Baensch, A. & Cleverley, J.S. (2015). Drilling powders produced during diamond drilling offer an opportunity for analyses in near real time. Retrieved from: https://www.researchgate.net/publication/280527729_Drilling_powders_produced_during_diamond_drilling_offer_an_opportunity_for_analyses_in_near_real_time

Walker, S. & Millheim, K. (1990). An Innovative Approach to Exploration and Exploitation Drilling: The Slim-Hole High-Speed Drilling System. Journal of Petroleum Technology - J PETROL TECHNOL. 42. 1184-1191. http://doi.org/10.2118/19525-PA