24-068

Ore Control Technological Innovations at Peña Colorada Mine

M. Marín-Pasillas
Peña Colorada, Colima, México

H.R. Hernandez-Guerrero
Peña Colorada, Colima, México

S. A. Robles-Salazar
Hexagon Mining, México

P. J. Pompilla-Rosales
Hexagon Mining, Perú

INTRODUCTION

Peña Colorada is a company dedicated to the exploration, exploitation, and beneficiation of iron ore, serving the national steel industry. Established in 1975 as a state-owned enterprise, it transitioned to operating as a private organization in 1991. It is jointly owned by two investors, ArcelorMittal and Ternium, each holding a 50% stake. The mining operation is situated in the municipality of Minatitlan, in the northwestern part of the state of Colima, Mexico (Figure 1).

It comprises an open pit mine and a concentrator, covering an area of approximately 2,300 hectares. The pellet mill is in the town of Manzanillo, Colima state, a port on the Pacific coast, about 46 km southwest of the mine. The pellet mill occupies its own property with a total area of 60.4 hectares. A gravity-driven concentrated slurry pipeline connects the mine and the pelletizing plant, located at an average elevation of 1,020 meters above sea level and 20 meters above sea level, respectively. Currently, Peña Colorada produces 4.1 million tons of pellets and 0.4 million tons of iron concentrate annually.

In 2018, due to a change in the cutoff grade, the processing volume of the beneficiation plant increased from 9 million tons to 16 million tons annually. This led to a greater amount of information to process and characterize the ore extracted from the pit before its processing in the beneficiation plant. Consequently, Peña Colorada sought new ore control technologies to enhance ore selection, optimize human resources and data management, as well as minimize discrepancies between planning and execution. To ensure adherence to quality agreements with stakeholders, it is crucial to understand the ore characteristics before initiating mining activities.

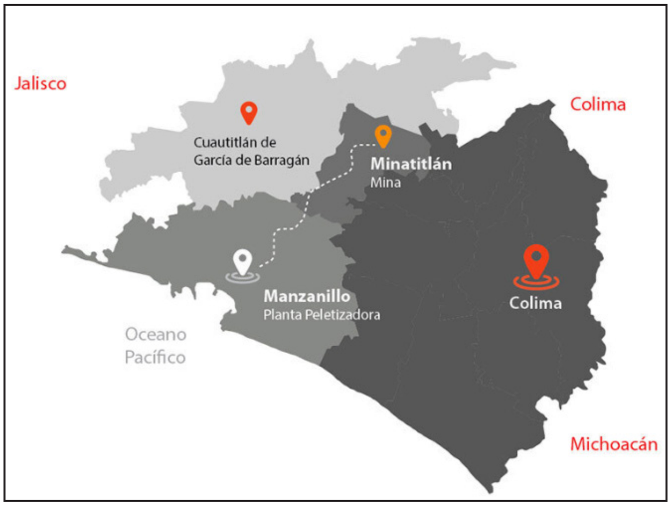


Figure 1. Project location

PROJECT OVERVIEW

In mining, operations engineers and geologists process extensive data to extract valuable information from the field. Their role is to transform this data into actionable knowledge, guiding crucial decisions for mining execution and production monitoring. Efficient communication tools are vital for conveying these decisions to stakeholders. This document explores how the adoption of a new Ore Control (OC) technology addresses these challenges, enhancing selectivity, performance, and data management while minimizing planning-to-execution variation. OC technology drives comprehensive operational improvement.

DATA SOURCES

Reverse Circulation data

The database covers the years 2016 to 2023. Reverse Circulation (RC) drilling is performed on a 10 × 10 m grid. The drilling is done at the bench level, with each sample having the same length as the bench (14 m) constituting a composite. The process involves obtaining information on magnetic iron (FeM) and total iron (FeT) grades, as well as chemical characteristics (Al_2O_3, CaO, MgO, P, S, SiO_2).

Block Model Information

For this study the follow items were interpolated from the RC drilling database (FeM, FeT, Al_2O_3, CaO, MgO, P, S, and SiO2). Three block models with different supports were created to observe the behavior of the tonnage and compare it with the tonnage reported by the dispatch system. The goal was to choose the block model with the least variation.

ABOUT THE PROCESSES

Previous Process

The primary area for improvement in the preceding process lies in the absence of an ore control block model. As a result, computations were conducted externally, necessitating manual data entry on paper or in Excel, which introduced complexities across various aspects of the workflow. Initially, the sampling information was collected by the geology department, each with an identification card, was submitted to Peña Colorada's internal laboratory for analysis. The laboratory staff manually recorded the results to be handed over to the mine planning personnel. The complete set of manual processes has the potential to introduce human errors, rendering it both observable and unreliable. Finally, the mine planning personnel used this information and manually entered it into an Excel file to calculate grades and chemical characteristics per blast (mining cuts) to subsequently define the mining cuts. Following this process, for each RC, the name, grades, and other characteristics were manually entered. This work was done per RC, and a DXF file was created to visualize them (Figure 2). When a new calculation was needed, such as modifying mining cuts, this process took hours to recalculate.

The previous process shows in Figure 3.

Actual Process

The current process utilizes an ore control block model that is rapidly updated through a workflow using MinePlan Axis. Calculations for obtaining grades, tonnage, and other characteristics of mining cuts are quickly performed using MinePlan Planner. Initially, samples collected by the geological department, each with an identification card, are sent to the internal laboratory of Peña Colorada for analysis. The results generated by the analysis team are used to feed the SQL database, and there is no manual manipulation of the results. The information is updated in the Drillhole Manager database (name, coordinates, date, etc.). The ore control model is updated with Axis, and finally, the users digitize, analyze, and attribute mining polygons with Planner (Figure 4).

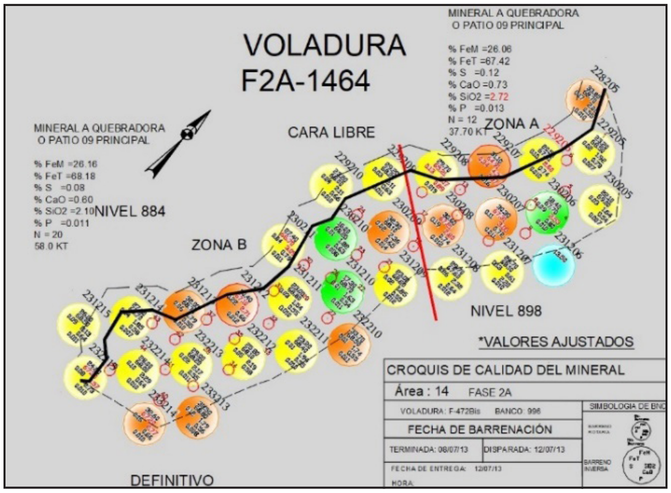


Figure 2. Old blasting sketch

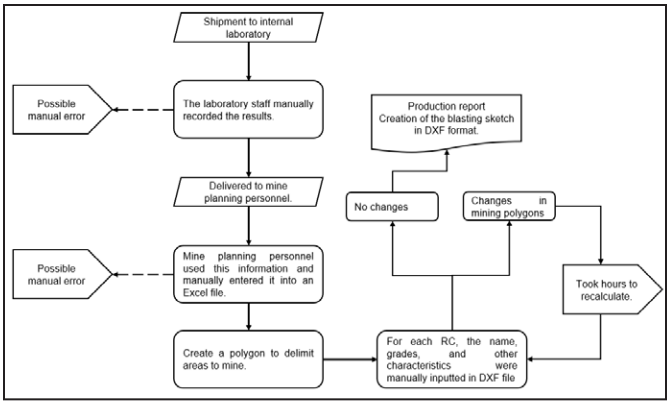
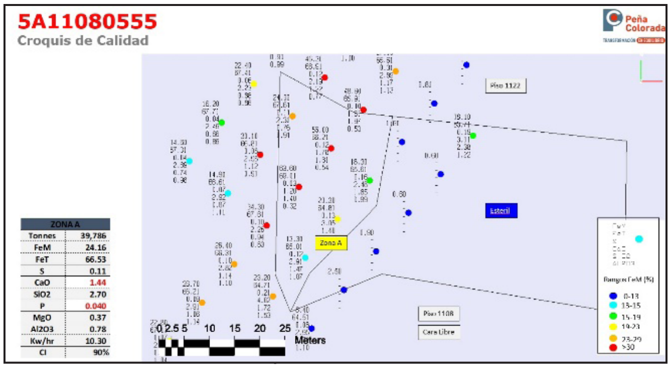


Figure 3. Previous process

The actual process shows in Figure 5.

The workflow of the Ore Control (OC) process through Axis, is known for its standardized, highly configurable, and auditable. This new process incorporates various tools that effectively address the challenges encountered with the previous system (Figure 6). The following processes are calculated in Axis:

1. Initialize bench.
2. Compositing.



ZONA A	
Tonnes	39,786
FeM	24.16
FeT	66.53
S	0.11
CaO	1.44
SiO2	2.70
P	0.040
MgO	0.37
Al2O3	0.78
Kw/hr	10.30
CI	90%

Figure 4. Actual blasting sketch

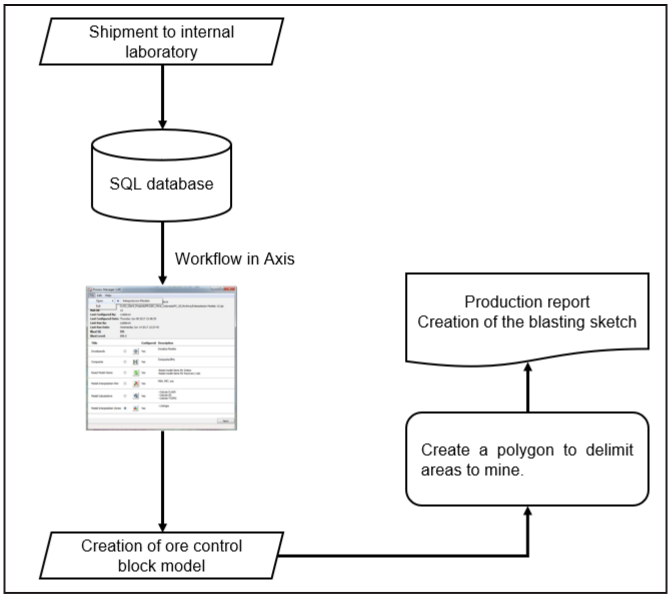


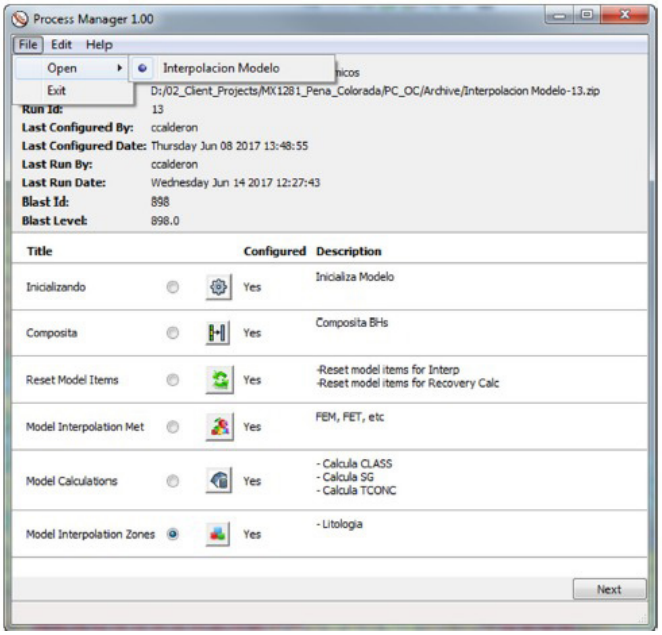
Figure 5. Actual process

3. Reset model items.
4. Interpolation of grades.
5. Calcs in block model.
6. Interpolation of zones.

To ensure the selection of the optimal block model size, a preliminary verification was undertaken. Three block models with different supports were created to observe the behavior of the tonnage and compare it with the tonnage reported by the dispatch system. The goal was to choose the block model with the least variation. The bench height is 14 m, the analysis focused on changing only the “X” and “Y” axes. The decision was made to explore three models, as shown in the Table 1.

The following steps were taken to analyze the tonnage behavior:

1. The mining cuts, were encoded onto the three block models ensuring at least 50% of their volume of block is inside the polygon and were assigned in the variable (PMIN) a value of 1.
2. The FeM values from the RC were interpolated onto the block model using the following interpolation parameters:
   - Interpolation method: Ordinary kriging
   - Modeling: Spherical isotropic variogram
   - Parameters: nugget = 0, search range = 30, and sill = 1.
3. With the interpolated FeM values based on the defined criteria, density was calculated using the following formula:



nicos
D:/02_Client_Projects/MX1281_Pena_Colorada/PC_OC/Archive/Interpolacion Modelo-13.zip
Run Id: 13
Last Configured By: ccalderon
Last Configured Date: Thursday Jun 08 2017 13:48:55
Last Run By: ccalderon
Last Run Date: Wednesday Jun 14 2017 12:27:43
Blast Id: 898
Blast Level: 898.0

Title		Configured	Description
Inicializando	○	Yes	Inicializa Modelo
Composita	○	Yes	Composita BHs
Reset Model Items	○	Yes	-Reset model items for Interp -Reset model items for Recovery Calc
Model Interpolation Met	○	Yes	FEM, FET, etc
Model Calculations	○	Yes	- Calcula CLASS - Calcula SG - Calcula TCONC
Model Interpolation Zones	●	Yes	- Litologia

Figure 6. Workflow in Axis

Table 1. Model blocks dimensions and names

Block Size	File Name PCF	File Name 15
7.5 x 7.5 x 14 m	PC7510.dat	PC0315.dat
5 x 5 x 14 m	PC0510.dat	PC0115.dat
2.5 x 2.5 x 14 m	PC2515.dat	PC0215.dat

$$SG = \left(\frac{2511.35 + (31.383 \times FeM)}{1000} \right)$$

This formula is a simplified version applied to the long-term model, where the mineral percentage in the blocks is not considered. For the Ore Control model, contacts are constrained by reverse circulation drilling, resulting in a unique value for each block without dilution of the mineral percentage. Three reserve logics were created to compare the three models. Once the processing of the three models

Table 2. Tonnage comparison obtained for each model, compared to the tonnage of the dispatch system

	Block Size		
	5m x 5m x 14m	2.5m x 2.5m x 14m	7.5m x 7.5m x 14m
Bench	Tonnage	Tonnage	Tonnage
660	63,099	60,747	55,586
842	935,298	935,048	928,185
856	968,491	978,031	945,676
870	1,766,393	1,764,081	1,757,424
884	1,152,273	1,144,678	1,138,934
898	480,185	478,862	484,440
912	1,823,744	1,825,033	1,814,331
926	2,701,473	2,703,083	2,694,727
940	1,316,318	1,316,154	1,305,881
Total	11,207,274	11,205,718	11,125,185
Total (Dispatch System)	**10,781,433**	**10,781,433**	**10,781,433**
Variation	**-3.97%**	**-3.96%**	**-3.21%**

was completed, a comparison was made between the estimated tonnage by model and the tonnage reported at the crusher by the dispatch system. The mining cuts mined by bench were employed for this purpose.

- The reserves were used to calculate the tonnage of the mining cuts by bench.
- The results obtained from each ore control model are shown in Table 2, including the tonnage obtained from these mining cuts through the dispatch system. The last row displays the variation between them.

Based on an analysis of the results, it can be concluded that the 7.5 × 7.5 × 14 m model exhibits the least variation. The block size selected was 7.5 × 7.5 × 14, as it resulted in the least variation in tonnages.

After selecting the appropriate size for the block model, the ore control model workflow is divided into the following steps.

1. Initialize bench.

Define one or multiple benches to be used in the block model for the update, as well as the bench for filtering the drillholes for interpolation.

2. Compositing.

The RC were composited to a 14-meter support (bench length).

3. Reset model items.

Perform a reset on the items involved in the interpolation process (FeM, FeT, Al2O3, CaO, MgO, P, S, and SiO2), as well as reset the items that will calculate recoveries.

4. Interpolation of grades.

Interpolation has been carried out using the following steps:

- All items were interpolated from the RC database (FeM, FeT, Al2O3, CaO, MgO, P, S, and SiO2). Each item was interpolated in a separate run.
- A generic isotropic variogram (same range in all directions) with nugget = 0, sill = 1, and range = 30 m was used.
- A 30 m search range was used to comply with the 10 × 10 grid spacing (3 times the spacing). Interpolation was performed using a spherical search of 30 m.
- A maximum of 12 composites per block were used, approximately equivalent to two data circles for each interpolation point.
- The kriging variance (VAR) was saved only for the FeM run. This would determine which blocks would be included in the model.

The kriging variance was calculated based on a variogram and the location of the RC. Since a sill of 1 was used, the variance would have values between 0 and 1. If a 3D model view is displayed, areas with a variation greater than 0.6 will clearly show blocks without nearby drill holes. Therefore, after the interpolation, a calculation is performed to reset all blocks where the variance is greater than 0.6. Figure 7 illustrates Ore control model.

After this, the following process was carried out:

- A calculation adjusted the values of the 8 grade elements when the variance (VAR) exceeded 0.6. Additionally, the SG value was set back to a default value of 2.51, considering FeM=0 using the previously mentioned formula
- To validate the model, a tonnage-grade curve was generated for FeM and FeT between assays and the model, where it can be observed that both follow the same trend.

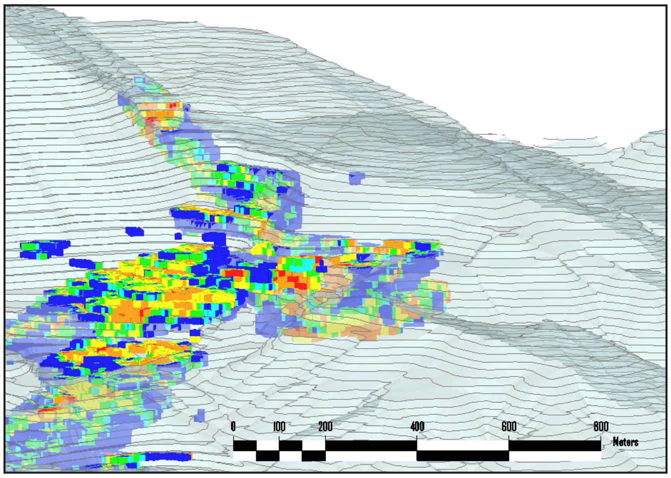


Figure 7. Ore control model

Table 3. Composite statistics

	Valid	Min	Max	Mean	Standard Desviation	Variance	Coefficient of Variation
FEM	11,438	0.000	62.300	20.614	11.220	125.910	0.544
FET	8,641	56.110	71.000	67.682	1.700	2.921	0.025
Al2O3	3,629	0.000	3.400	0.910	0.430	0.189	0.475
CAO	8,641	0.210	6.250	0.760	0.314	0.098	0.411
MGO	3,629	0.000	2.700	0.375	0.249	0.062	0.661
P	8,641	0.000	0.114	0.015	0.111	0.000	0.720
S	8,641	0.000	2.760	0.120	0.167	0.028	1.394
SIO2	8,641	0.000	8.740	2.492	0.980	0.972	0.396

Table 4. Model statistics

	Valid	Min	Max	Mean	Standard Desviation	Variance	Coefficient of Variation
FEM	30,538	0.000	60.110	19.446	9.897	97.944	0.509
FET	30,306	57.540	70.610	67.449	1.564	2.445	0.023
Al2O3	16,402	0.000	3.072	0.881	0.378	0.143	0.429
CAO	30,306	0.363	4.699	0.795	0.296	0.088	0.372
MGO	16,402	0.000	2.103	0.352	0.205	0.042	0.581
P	30,306	0.000	0.114	0.017	0.011	0.001	0.642
S	30,306	0.000	2.287	0.131	0.152	0.023	1.162
SIO2	30,306	0.926	7.714	2.599	0.905	0.819	0.348

- Box plots were reviewed between composites and the model for the rest of the elements, where similarly, the trend between them remains consistent.

It should be noted that it is possible to have FeM values in a RC but no values for the other elements. Since FeM is used as the control grade and its kriging variance as the control item, interpolated blocks will be obtained with the additional 7 items, where there will be RCs around those blocks that do not have values for these 7 items. These blocks will be interpolated by the farthest RCs that have FeM values. If this is not acceptable, separate runs should also be performed, saving the kriging variance for each item separately, and then resetting that item based on a determined variance value for each independent item (like how values are reset with VAR < 0.6).

5. Calcs in block model.

In this step are calculate the following variables:

- Using classification criteria, the results are saved in the CLASS item.
- The specific gravity calculation is derived from a regression formula and is saved in an SG item. With the interpolated data of FEM and the specific gravity calculation.
- The mineral concentrate is then calculated using the mineral recovery formula provided by the mine's processing area, and the result is stored in the TCONC item.

6. Interpolation of zones.

When there is a change in waste lithology in the area due to mapping or updating of the lithological model, the specific gravity of the lithology is assigned. This specific gravity is determined through density sampling in the model.

Validation of ore control model

An exploratory data analysis (EDA) was conducted on the reverse circulation sampling (EDA 2016) and the data obtained from the Ore Control model (Implemented 2023). The comparison was made through a histogram and a tonnage-grade curve. (Figure 8 and Figure 9)

The Table 5 shows an adjustment in the means is observed due to the implementation of the model, showing a slight smoothing effect that is not a significant impact.

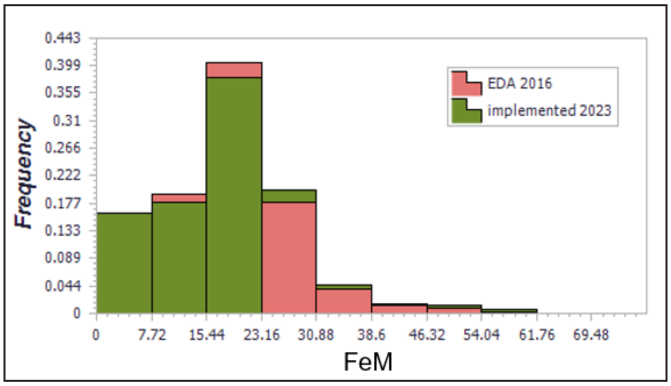


Figure 8. Histogram of the 2016 database (EDA 2016 in red) vs. the database after improvement in 2023 (Implemented 2023 in green)

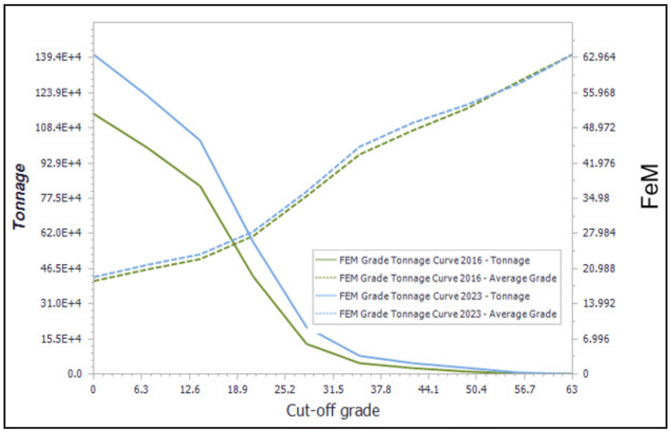


Figure 9. Graph of tonnage-curve vs. grade (EDA 2016 in green) compared to the database after improvement in 2023 (Implemented 2023 in blue)

Table 5. Statistics for the 2016 database (EDA 2016) vs. the 2023 database (Implemented 2023)

Summary Statistics	EDA 2016 FeM	Implemented 2023 FeM
Valid Data	25,544	31,350
Total Data	25,743	31,579
Missing Data	199	229
Invalid Data	199	229
Minimum	0.010	0.000
Maximum	63.600	63.600
Mean	17.740	18.403
Variance	88.550	103.846
Standard Deviation	9.410	10.190
Coefficient Of Variation	0.530	0.554
First Quartile (Q1)	11.900	12.000
Median (Q2)	18.400	18.900
Third Quartile (Q3)	23.000	23.900

Table 6. Table of comparison blast before of the implementation and after the implementation

	Method before implementation			
Blast name	KTonnes	FeMag	FeT	SiO_2
2C09120667MA1	30.280	24.860	67.940	2.280
F1A-447	54.170	24.030	67.210	2.710
2C09120550MA1	78.390	24.390	66.840	1.810

	Implementation			
Blast name	KTonnes	FeMag	FeT	SiO_2
2C09120667MA1	42.913	27.199	68.454	2.053
F1A-447	37.680	19.970	66.640	2.940
2C09120550MA1	79.050	24.580	66.730	1.880

Delimitation of mining cuts

The comparison between blast sketches before the improvement (calculated with Excel) and those with the Ore Control model indicates several improvements. The preparation time for blast sketches has been reduced by over 50%. The time required for developing monthly and quarterly mining plans has also seen a reduction. Additionally, it facilitates a more dynamic scheduling of surfaces for mining. The model enables immediate retrieval of grade and chemical characteristics (reports) by simply having the mining cut and the ore control model (Table 7).

For sequencing, it is essential to generate a half-bench polygon for long-duration phases that accurately represents the solid of each extraction phase. Mining cuts are created for sequencing to optimize the best representative grade and tonnage. Figure 10, Figure 11, Figure 12, and Figure 13

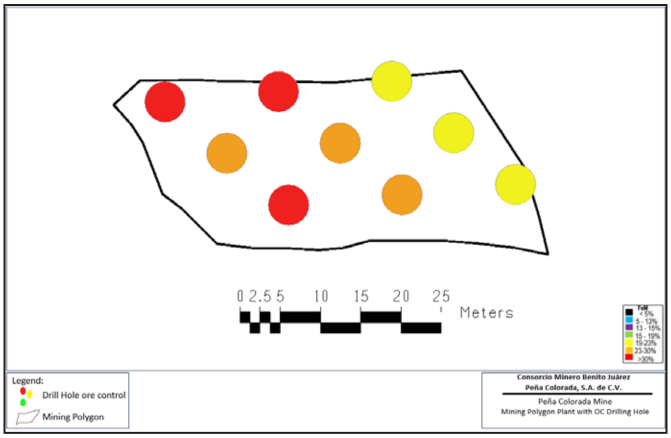


Figure 10. Blasting sketch with the previous methodology

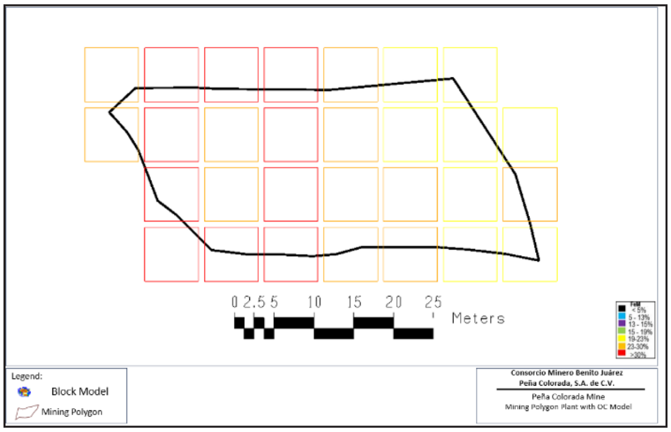


Figure 11. Blasting sketch with Ore Control model

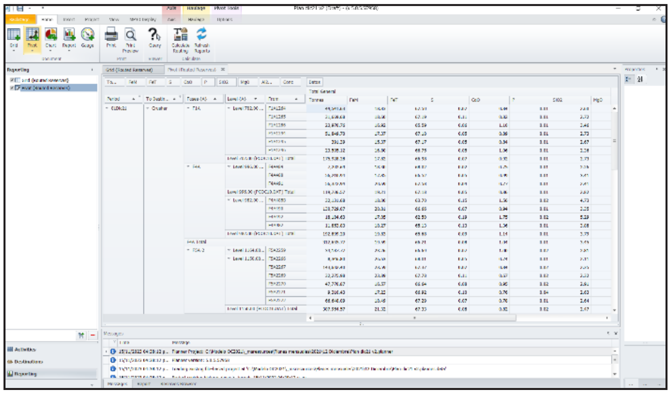


Figure 12. Planner interface with report of different polygons

Table 7. Report from three blasts

Cut	Tonnes	Volume	FEM	FET	S	CAO	SIO2	P	AL2O3	MGO
2C09120550MA1	79,057	24,105	24.582	68.734	0.054	0.678	1.879	0.011	0.607	0.241
2C09120667MA1	42,913	12,767	27.199	68.454	0.083	0.776	2.053	0.010	0.800	0.307
F1A-447	37,685	12,021	19.970	66.639	0.155	0.971	2.939	0.013	1.015	0.359
Grand Total	159,655	48,892	24.197	68.260	0.082	0.764	2.130	0.011	0.745	0.284

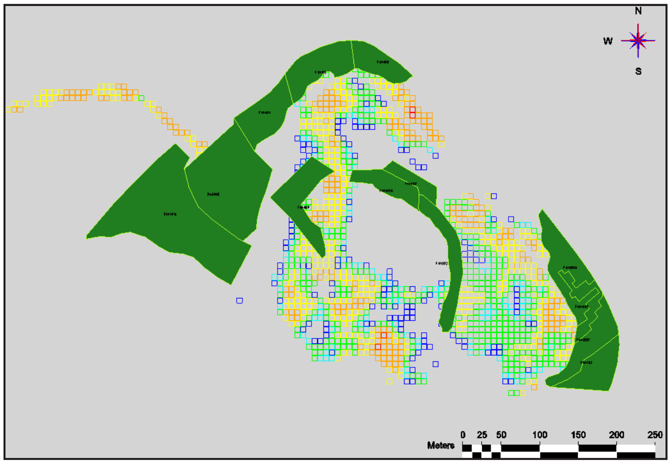


Figure 13. Polygons from planner matching with ore control block model

show a sketch of a blast (mining cut) with grade calculation using the previous methodology (Excel) and with the implementation of the ore control model.

Results of Implementation

It is essential to highlight that, ideally, the grade and chemical characteristics of the material to be extracted should be known prior to monthly planning to ensure greater precision in operational results, optimize economic resources, and fulfill quality agreements with shareholders.

1. The implementation of an ore control block model significantly reduced blast sketch time from over 2 hours to just 2 minutes.
2. Enhancing the determination of grade, qualities, and tonnage. Utilizing MinePlan™ Axis and Planner tools.
3. The mining plan can now be easily developed with traceability, optimizing tool utilization compared to the previous manual and time-intensive approach.
4. After an analysis of potential solutions, it was decided to implement an enhancement through the generation of an ore control block model, along with an application that would facilitate the automation of its updates.
5. The objective is to shorten the information processing times, make decision-making more precise and dynamic, and achieve other associated benefits.

CONCLUSIONS

The improvements implemented in the Ore Control process through the generation of the ore control block model allows for a reduction in blast sketch preparation times. It provides mining planners with a valuable tool for creating weekly, monthly, and quarterly feeding plans to the crusher. Standardizing this process shortens processing times and enhances the quality control of information, reliably generating data for ore control.

1. The Ore Control improvement implementation has been documented to ensure replicability in the event of personnel changes. The process is also auditable, enabling the identification of areas for improvement and the implementation of enhancements. The automation of the process helps reduce potential human errors by decreasing the amount of manually entered information.
2. The Ore Control model allows for reconciliations between it and the resource model, as well as the results of feeding to the crusher.
3. In open-pit mining involving iron deposits, various modeling and design methods can be implemented with user-friendly tools.
4. The automation of the ore control model update process through the HxGN module, MinePlan™ Axis, addresses challenges encountered in the evaluation of open-pit mining operations and subsequent short- and medium-term mine planning.

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24-069

Outlining a Roadmap for the Deployment of a Digital Twin System for the San Xavier Mine Laboratory

Víctor O. Tenorio
University of Arizona, Tucson, AZ

Angelina Anani
University of Arizona, Tucson, AZ

Gail Heath
University of Arizona, Tucson, AZ

Nathalie Risso
University of Arizona, Tucson, AZ

Dean Riley
University of Arizona, Tucson, AZ

Nilufer Akbulut
University of Arizona, Tucson, AZ

James Werner
University of Arizona, Tucson, AZ

Implementing a Digital Twin at the San Xavier Mine Laboratory (Sahuarita, AZ), requires a network redesign with a robust architecture. The goal is to create an ecosystem in where all personnel and equipment can be monitored in real-time from the University of Arizona campus, visualizing the site in a digital terrain model. A wireless mesh will help to test robots with autonomous features. Expected outcomes include data retrieval and analytics, the evolution of communications and safety protocols, tele-operation, and an innovated approach for managing the site with new supervision challenges. A timeline with expected commissioning benchmarks is also included.

INTRODUCTION

In recent years, computer technologies for underground mines have experienced a major development in terms of versatility, effectiveness, and information management. Internet of Things can be found virtually everywhere, allowing conventional equipment to provide essential data for analysis and process improvement. Combining hardwired and wireless network configurations, it is possible to overcome the classic limitations of data/signal transmission in underground works, and in turn boost up operations with supervision, surveillance teleoperation and autonomous systems for the benefit of safety, productivity and cost reduction. From all these solutions, Digital Twins appear as a highly useful solution for not only observe operations remotely, but to actively participate in the excellent of operations. Implementing Digital Twin technologies may sound easy in theory, however it may take several steps and trial attempts for a seamless configuration, until extending our reach from a control room to a remote mine operation, and effectively improving the overall performance of equipment and personnel, while keeping safety levels and achieving production goals. This paper center in the required steps to implement from scratch a Digital Twin system for the supervision of the San Xavier Mine Laboratory, located in Sahuarita, AZ, from the University of Arizona Campus, in Tucson, AZ. Several challenges include identifying the proper technologies required, the network-to-network communications protocols, the supervision, safety of operations and the adequate asset management, so that the model produced could be sustained effectively, and later scaled to planned future expansions in the site.

THE SAN XAVIER MINE LABORATORY

With one of the nation's most sophisticated research hoisting systems, two declines for access of rubber-tired vehicles and legacy rail haulage access, the mine features four levels of underground workings to a depth of 250 feet. This unique site has attracted projects critical to national defense, geosciences, mine safety and miner rescue. (LIMR (2023). In 2020, a major expansion included a decline with a portal of 15 × 15 feet section, and a total projected length of 1,000 feet. In recent times, many sensors have been placed along the excavation, opening the possibilities