R. E. Vivas (Hexagon Mining, USA) with J. A. Villa and Jose L. Portugal R. (Peña Colorada, Mexico), discuss the importance of aligning evolving mine planning methods with mining operations.

INTEGRATION, THE KEY TO SUCCESS

Mine plans must be flexible and adaptable to respond to changes in operations and the business environment. As mining technology evolves, the whole value chain can be redefined. Aligning mine planning with mine operations is critical to realising maximum project value.

Hexagon Mining's (Hexagon) mine planning software and operation solutions are used to this end at Peña Colorada in Mexico. Peña Colorada is one of the country's largest iron ore operations. Located in the state of Colima, Peña Colorada's operations consist of an opencast mine in Minatitlán and a pellet plant in the port city of Manzanillo. The company produces about 30% of the iron ore in Mexico. This project generates approximately 1200 direct jobs and 3000 indirect jobs, significantly contributing to the local economy. Peña Colorada invests in its local communities through educational programmes, scholarships, university agreements, social development and environmental agreements.

Despite a production capacity of 4.1 million tpy of concentrate, Peña Colorada faces declining ore grades. In response, the company had to expand production even further. This expansion created challenges that were overcome by the adoption and application of new technology and improvements in geomodelling, mine planning and mine operations.

The successful implementation of these technologies paid for itself many times over and led to significant improvements in production and performance. Operating costs were lowered and the variance between planning and execution was reduced.

The benefit of technological innovations

Most mining projects follow the logic of 'mining the next best ore'. Consequently, head grades tend to decline over the life of the mine. For Peña Colorada, a decline in head grade combined with a decline in iron ore prices forced the operation to adapt to a new business environment and adopt new technologies to face these challenges.

The first step was to increase the confidence and reliability of the resource model. This involved additional drill hole

campaigns, coupled with more detailed modelling techniques. Once the block model was completed, new optimisation studies and production schedules were evaluated with new optimisation tools that improved many aspects of the mine plan.

Peña Colorada's block model has undergone three expansions to reflect additional information not available in the past. The model has expanded to the east and southwest. The latest model expansion increased the total number of benches to 98 because of positive exploration results. New geotechnical studies were prepared, which provided new guidelines for pit slope design, and new technology was implemented to monitor ground movement and slope stability. Two sectional block model views in Hexagon's 3D visualiser, MineSight 3D, along with the pit designs and geologic solids are shown in Figure 1.

Peña Colorada implemented a new fleet management system to monitor the operation and ensure plan execution and compliance, thus capturing in the field the value of the project as forecasted in the mine plan. The variance between plan and reality has been significantly reduced with the adoption of Hexagon's mine planning software and fleet management system. The implementation of technologies narrowed the gap between what is and what should be, and unlocked and realised project value.

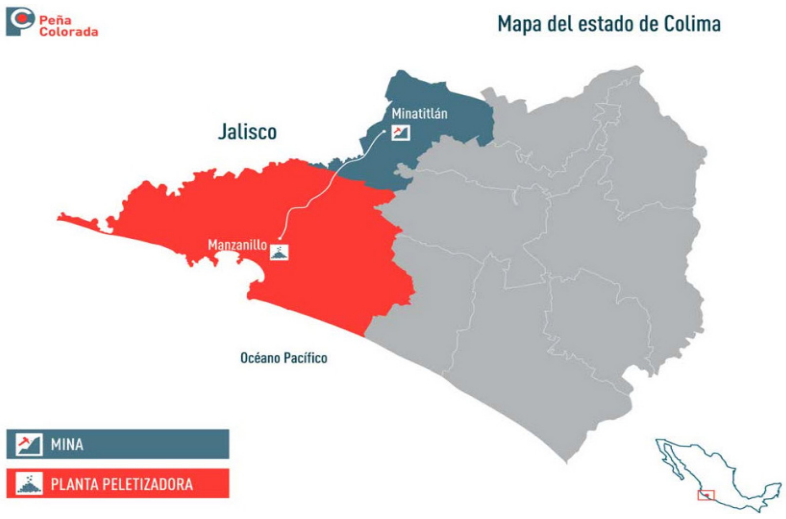

Figure 1. Model views in Hexagon's MineSight 3D.

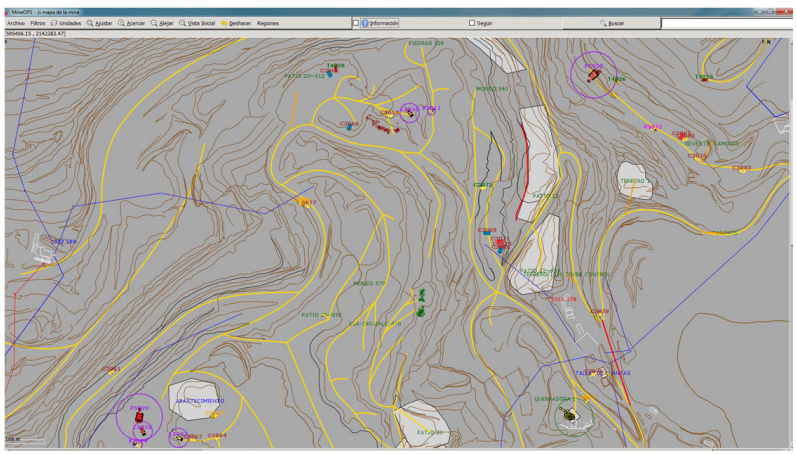

Figure 2. Real time mine monitoring.

Mine planning

The Peña Colorada deposit comprises three main geologic structures affected by a moderate fault system, as shown in Figure 4. These three structures control the geology in terms of mineable material characteristics.

The mineral resource model was constructed in two stages: construction of the geological model and the numerical modelling of attributes.

The construction of the geological model involved three steps:

- Processing of the drilling campaign.
- Accounting for the minimum scale of geological interpretation.
- Construction of the surrounding solids.

The drilling campaign was processed through Hexagon's mine planning suite, MineSight; specifically, its drill hole manager, MineSight Torque and MineSight 3D.

The geological envelopes were constructed as geometric solids using MineSight Implicit Modeler (MSIM) to accurately characterise the geological contacts.

MSIM has since been replaced by Geologic, which leverages the power of implicit modelling by sequencing surfaces and solids to create an airtight geological model. The numerical modelling of attributes comprises the estimation of grades by localised ordinary kriging.

Once the block model was completed, new optimisation studies were evaluated with MineSight Economic Planner (MSEP) and new production schedules were completed with MineSight Schedule Optimiser (MSSO). This improved many aspects of the mine plan. For example, MSSO was used to evaluate and optimise the dump discharge plan.

MSEP is used mainly to determine the economic pit limits based on the value of the block and the slope recommendations.

MSEP can model complex slopes by zone, and by zone and azimuth. This functionality was not available to Peña Colorada in the past, and it allowed the company to follow the slopes' recommendations in its pit designs for a safer and more productive operation.

One of the issues encountered regarding the pit optimisation process, was the time required to run the economic evaluation. This has improved over time with smarter and more powerful engines. However, the Lerchs-Grossmann algorithm that was the standard for many decades has been challenged by the arrival of new algorithms. More specifically, there are pit optimisation cases in which the Pseudoflow algorithm can produce the same results as the LG in a fraction of the time.

For more than 40 years, Peña Colorada has faced many challenges, some of which did not represent as much of a risk when the mine was operating at a higher cutoff. Once the mine started to transition into the low grade zones there was less room for error. In the past, Peña

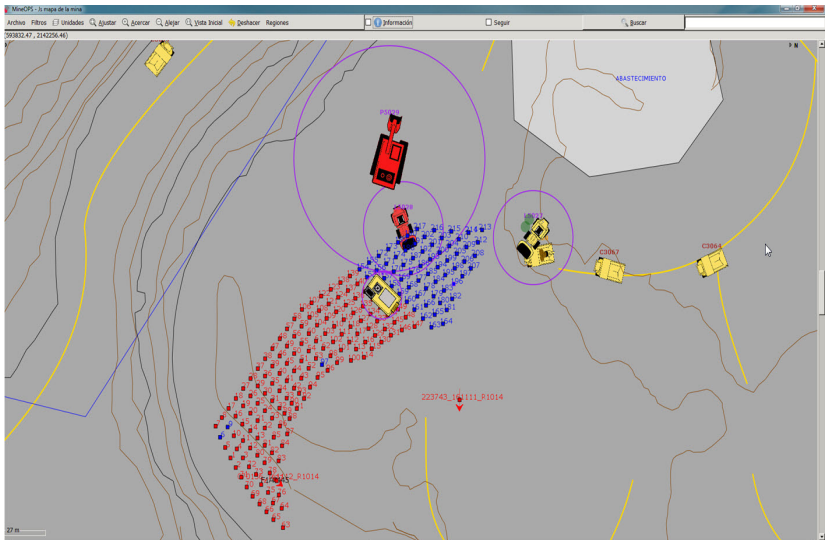

Figure 3. Actual drill progress and KPIs.

Figure 4. The Pena Colorada deposit comprises three main geologic structures affected by a moderate fault system.

Figure 5. High precision guidance.

Colorada used in-house tools (Rescon & Resc) for generating annual mine plans. These in-house tools were complemented with Excel and AutoCad. However, these manual tools did not optimise the value of the project, so Peña Colorada turned to MSSO, which helped the mine optimise the cutoff grade and material routing strategy, meet quality/quantity targets, and integrate the extraction plan with the haul plan and the dump plan all in one tool. All these aspects of the mine plan have a great impact on the value of the business.

For example, after evaluating multiple alternatives with MSSO, it was clear that a mine expansion was required to maximise the value of the project. The mill throughput was almost doubled, while new equipment was acquired to realise the increased production from the pit. MSSO was used to evaluate this expansion project and the acquisition of bigger shovels (P&H 4100 XPC) and bigger trucks, (CAT 789C and 793F).

Mine expansion projects costs are in the order of hundreds of millions of dollars to a few billion dollars. Investing in an optimisation tool like MSSO is easy to justify since it can guide important capital investment decisions and it costs less than the tyres of an off-highway haul truck.

MSSO can replicate the schedule of any opencast truck and shovel operation and improve its value and attainability since it has both optimisation and manual controls that produce a practical plan. In the past, there were long-term schedules that were optimal, that could not be implemented in operations and there were short-term schedules that were practical but not optimal. MSSO closed that gap and produced strategic and tactical schedules that are practical and optimal for an integrated mine planning vision across multiple planning horizons, providing a clear plan that can be realised in operations.

Similarly, MSSO was used to evaluate and optimise the dump discharge plan. The results of the optimisation generated a plan with less stripping required in the earlier periods and a combination of short and long dumps. This balanced the truck hours over the life of the schedule and reduced the number of trucks required. The estimated gains derived from this optimisation study amounted to approximately US$35 million in project value.

MSSO has positively disrupted the mine planning landscape. The transformation at Peña Colorada has been significant in the mine planning department. MSSO allowed the evaluation of multiple alternatives, blends and mine sequences much faster than before. The programme works with multiple material types, scheduling classes, reserve classification, rock types etc., allowing the engineer to analyse details that were not reflected before in the plans. The reports are easily created and configured. The truck requirements are calculated based on cycle times obtained from the field and corroborated by the fleet management system. The programme reports the haul distances required for fuel consumption and indicates when haul trucks must be replaced in the schedule. The rich reporting via analytical and graphical results allows for effective communication and understanding between the mine planning and other departments.

Fleet management system

Following the mine plan in operations was a big challenge at Peña Colorada prior to the implementation of the fleet management system (FMS). The ability to monitor in real time the location of the trucks, shovels, dozers etc., was a significant technological innovation to ensure that the plan stayed on track. Now, the mine planning engineer and operator can communicate and adjust to make changes as needed, thus reducing deviations from the plan. With the adoption of an FMS,

multiple reports can be created to report key performance indicators (KPIs) and measure performance.

Once the monitoring systems were implemented, people's behaviours changed, because they knew they were being observed and monitored. Prior to the implementation of the FMS at Peña Colorada there was little accountability on the operator side. Delays, extended breaks and missing equipment were not unusual. These factors add up and take a toll on productivity and profitability. Asset control and monitoring has made a drastic difference, and missing equipment is a thing of the past. The FMS optimises the haul cycle times and routes the trucks to the best destination based on material type, available routes and mine traffic conditions.

Figure 2 shows a real time screen capture from the FMS showing the trucks, excavators, dozers, haul routes, topography and structures. Five excavators and 26 haul trucks, plus dozers, drills and other equipment are monitored at Peña Colorada.

Previously, planners had to visit the field to physically inspect the drills for progress and note how many holes had been drilled, how many remained etc. Now they can view the blast pattern in real time and see how many holes have been drilled and how many remain. They can look at the KPIs of the drill and retrieve metrics on penetration rate, hole depth and hole profiles. The drills are equipped with high precision GPS, so it is no longer necessary to stake out the collars in the field. Peña Colorada is in a hurricane zone and thunderstorms pose a safety risk. An alert system changes from orange to red if a storm is approaching.

During red alert, topographers could not be in the field staking the collars to be drilled. Alerts could last 6 hours or more and drills would fall behind, and production would suffer. Now, the collar co-ordinates are passed from the planner to the operator digitally with high precision GPS systems, eliminating the need for the topographers to be staking out the collar locations in the field.

Figure 3 depicts a capture screen showing the blast pattern in real time, so planners can check the progress of the drill. The FMS displays the holes completed in red, the remaining holes in blue, and the KPIs for the drill. Operators and planners can communicate, and deviations can be adjusted as needed in real time.

The high precision guidance system allows for accurate blast hole location, monitoring of production data, and the hardware can be easily installed in the operator's cabin.

Production reports used to take many hours to complete and required staff dedicated for that purpose. Additionally, the information was communicated verbally and recorded by hand, which resulted in inaccuracies and errors, compromising the validity of the reports. Since the implementation of the FMS, production reports are produced with one click. The information is reliable and in real time.

The production reports generated by the FMS allow the monitoring of the operation and provide metrics to measure performance. Production reports are reconciled against the planning forecasts to ensure plan compliance. Thus, the variance between planning and execution can be understood, measured and reduced, so that maximum project value can be realised according to the business objectives of the organisation. GMR