Gestión y Economía Minera Ltda.

PERSPECTIVE N°10

MINING OPTIMIZATION

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MOTIVATION: COST REDUCTION IN THE MINING INDUSTRY

After the commodities supercycle, a time where the mining industry was mostly concerned about production issues, and the recent price drop experienced by commodities, most of the mining companies are in the middle of an adjusting phase: industry costs must adjust to the new commodity prices in order to reach acceptable profitability levels. This issue is especially critical for companies that managed to extend the life of their operations based on an expected high commodity prices, and now must decrease their costs to remain profitable.

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Leaving input prices aside (since they are usually not controllable by mining companies), the only way mining companies can reduce operational costs is through process optimization. There are several different tools which can be used to achieve this, always with the target of adding value to the business. Process optimization, in general, has two approaches: local and global or systemic. Additionally, given the multiple uncertainties associated with mining processes, it is sometimes necessary to integrate those variables into the different model elements. In this GEM Perspective, both approaches will be developed and their practical examples will be shown.

GEM, throughout its six years of experience, has developed optimization projects in both, local and systemic approaches and has been able to demonstrate that optimization is an effective tool to add value to the mining business.

OPTIMIZATION APPROACHES

OPTIMIZATION

In the mining industry, there are multiple processes with countless variables each. Furthermore, sometimes these variables are not known with certainty. This is the reason why process optimization becomes even more complicated and the use of specialized tools is required.

Currently in mining some decisions are made heuristically, thanks to the experience of the operators, professionals, and executives involved. Even when most of these decisions converge to the optimum or close to it, they often focus on a local level and do not consider the entire value chain of the company.

The first step to any kind of optimization is to identify areas for improvement. This can be done in different ways, such as brainstorming exercises within the team or with external agents. The next step is to model the optimization problem and solve it to find the optimal strategy with the chosen optimization tool. The third step is the implementation, which results should be evaluated, and if necessary rerun the optimization model until reach the desired results.

Due to the complexity of process optimization in mining, it is often necessary to separate the problem in parts. Isolated optimization of each part is known as local optimization. On the other hand, it is possible to identify some variables that can be modeled in a systemic way, considering the whole system or value chain. Such variables can be optimized in a holistic manner, taking into account the interactions between each thread. Using systemic optimization it is possible to ensure that the strategy found is also a global optimum.

LOCAL OPTIMIZATION

Local optimization becomes more relevant to highly complex problems, when there are bottlenecks or the processes are independent. Whenever a local optimum is sought, we must be careful to not affect downstream processes, since often the optimal variable of a process can affect the performance of the following.

In the past, GEM has had the opportunity to work with different mining operations doing local optimization focused on the entire business. One of these projects was a study of replacement of truck dump tray, where the analysis was focused on finding the best strategy in terms of costs by modeling the truck dump tray failure rate and the associated costs under uncertainty. To that end, the analysis considers not only operational cost but also capital cost and financial considerations at a cash flows level. The evaluation uses the concept of Equivalent Uniform Annual Cost (EUAC), standard methodology to analyze productivity in mining equipment and components. The EUAC is defined as:

$$EUAC = F \times \left(\frac{i(1+i)^n}{(1+i)^n - 1} \right) \qquad \textbf{(1)}$$

Where *F* represents the sum of the discounted cash flows, *i* the discount rate and *n* is the evaluation horizon. In the study the risk associated to EUAC was included in order to compare different maintenance strategies.

Different possible strategies were considered to find the final solution as shown in ***TABLE 1.***

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TABLE 1. CONSIDERED STRATEGIES

Strategy	Description	Asociated Costs	Risk and Benefits
Current Strategy	Purchase truck dump tray and general overhaul after failure	Purchase a new truck dump tray and the associated repair costs	The failure risk is assumed by the company
Lump Sum	Pays an annual/monthly fixed amount ensuring corrective repairing	Supplier have the same cost structure as the Current Strategy but he will charge a fixed price (which allows supplier margin)	The failure risk is assumed by the supplier
Dump Truck Tray Rental	Truck dump tray belongs to the supplier and an annual or monthly fee is paid for them	Similar to Lump Sum, but consider an additional return on investment of the dump truck	The failure risk is assumed by the supplier
Preventive Maintenance	Preventive maintenances are made after a fixed number of hours of use. This strategy also considers the corrective maintenance cost	The same structure of the Current Strategy with lower preventive maintenance cost and the loss of production during maintenance period	The failure risk is assumed by the company
Light Dump Truck	Use lighter truck dump trays with replacement in case of failure	Only consider the investment cost for buying a new light dump truck	The failure risk is assumed by the company and there is a potential benefit by moving more material
Cost Per Hour of Use	Similar to the strategy lump sum, but charge for time in use rather than chronological time	The supplier have the same cost structure of the Current Strategy but charge a unit cost per hour of use	The failure risk is assumed by the supplier

WHAT IS GAME THEORY AND WHAT IS IT USED FOR?

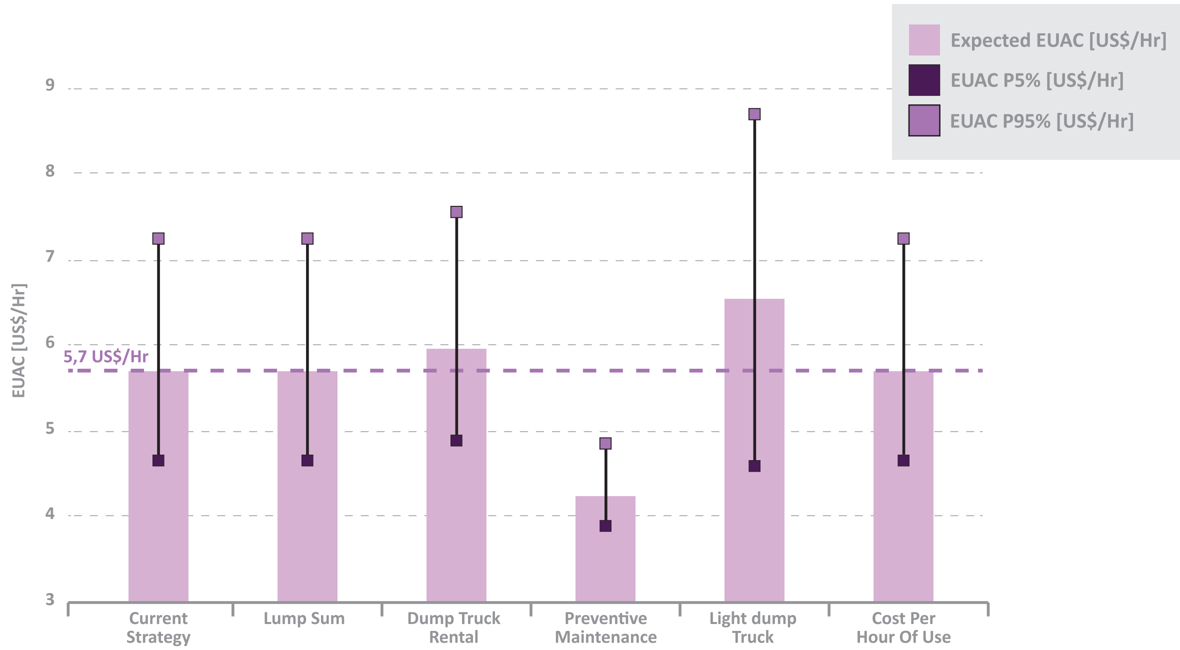
Game theory is an area of mathematics which uses models to study how decisions are made in situations where each side has different incentives. In practice, game theory is used to find optimal strategies as well as to predict behaviors under different scenarios. As an example, game theory is usually used to model the competition between companies with market power.

Among the risk considered, modeled uncertain variables were:

- Truck's availability
- Truck's utilization
- New truck dump trays' lifespan
- New light truck dump trays' lifespan
- Repaired truck dump trays' lifespan
- Preventively maintained truck dump trays' lifespan
- Light truck dump trays' additional capacity

Each uncertain variable was analyzed to fit a distribution that represents its behavior. By using these distributions and after many iterations on the developed model, the final results shown in ***FIGURE 1.*** were obtained, where hours represent the total hours that the equipment has been in use.

FIGURE 1 EUAC COMPARISON



After a sensibility analysis, it was determined that the strategy with the lowest expected EUAC and risk for the company was the Preventive Maintenance. This solution saves costs by 25% with respect to the Current Strategy.

FIGURE 2. OPTIMAL TIME TO PREVENTIVE MAINTENANCE

During the project, it was determined that the optimal time between preventive maintenances stood between 8,000 and 10,000 hours of use, as shown in ***FIGURE 2.***

This project is a clear example of the benefits of local optimization done independently from downstream processes. Additionally, for projects that include a bidding process it is possible to add a game theory analysis to find the optimal strategy for the company – meaning, the one which will allow for the best bidding results possible.

The systemic optimization refers to which considers the complete value chain...allows guarantee that the optimal strategy found correspond to the overall operation, and that takes into account all the possible interactions inside the operation.

GLOBAL OR SYSTEMIC OPTIMIZATION

The systemic optimization refers to which considers the complete value chain. This kind of optimization, unlike local optimization, allows guarantee that the optimal strategy found correspond to the overall operation, and that takes into account all the possible interactions inside the operation. Thus, it is possible that what used to be a local optimum not appears in the optimal global strategy.

An example of systemic optimization is the Mine-to-Mill concept. This concept refers to a systemic approach for the cost energy consumption in the comminution process. This concept was developed by the Julius Krutschnitt Mineral Research Centre (JKMRC) in Queensland, Australia (Adel, Kojovic, & Thornton, 2006). Due the different energy costs in drilling, blasting, crushing and grinding, this concept allows to find a global optimum for the cost of the energy consumption in the overall comminution process. The objective function of the optimization is as follows:

$$Min(E_{Drilling} * C_{Drilling} + E_{Blasting} * C_{Blasting} + \\ * C_{Grinding}) \\ + E_{Crushing} * C_{Crushing} + E_{Grinding} \qquad (2)$$

Where E_i is the energy consumption of the *i*th stage, and C_i is the energy unit cost of the *i*th stage.

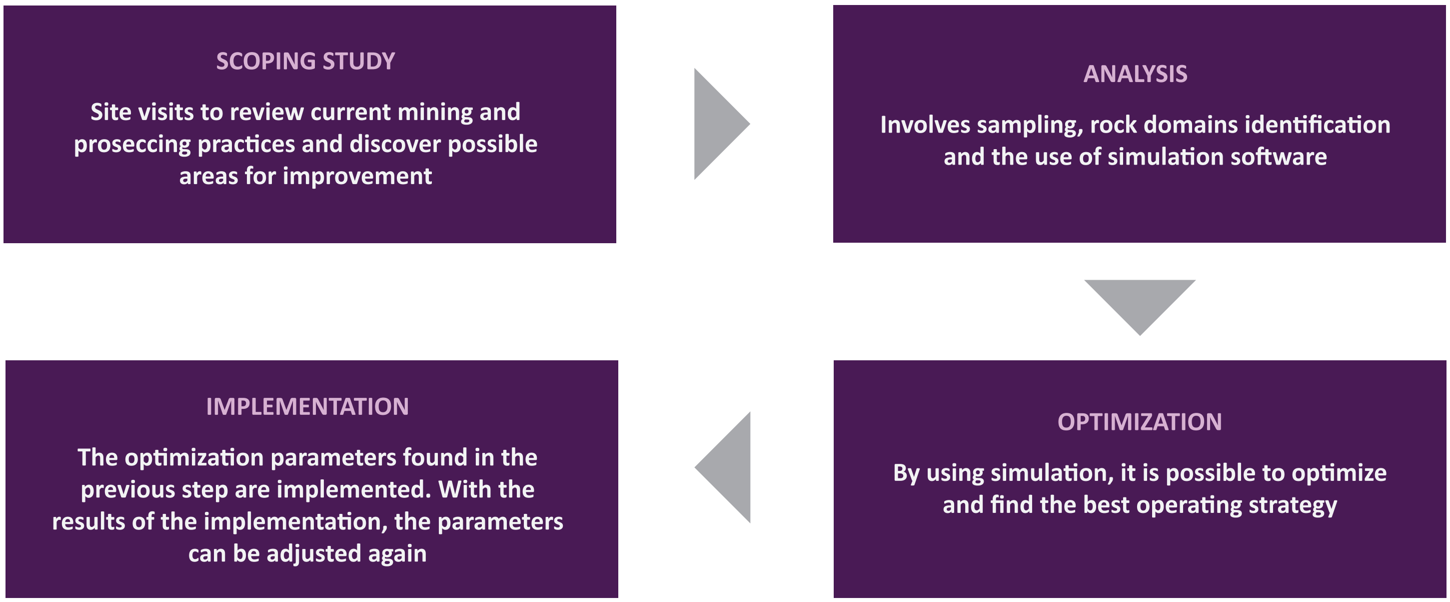
This approach comprehends stages of sampling and characterization, modeling, simulation and optimization. Unlike local optimization, a systemic approach allows to use the comparative advantages between the stages in order to obtain a better overall result of the operation. Frequently Mine-to-Mill optimization demands technology transfer to the industry.

The four steps of Mine-to-Mill optimization are shown in ***FIGURE 3.***

An example of this kind of optimization is the optimal blasting design in order to achieve lower costs as possible. This can be done by two ways: decreasing the energy consumption in crushing and grinding due a smaller particle size or increasing the plant throughput and thus obtain lower unit energy consumption. The process is iterative, as shown in ***FIGURE 4.***, and at the end of each cycle it has to be evaluated with the developed models appropriate adjustments.

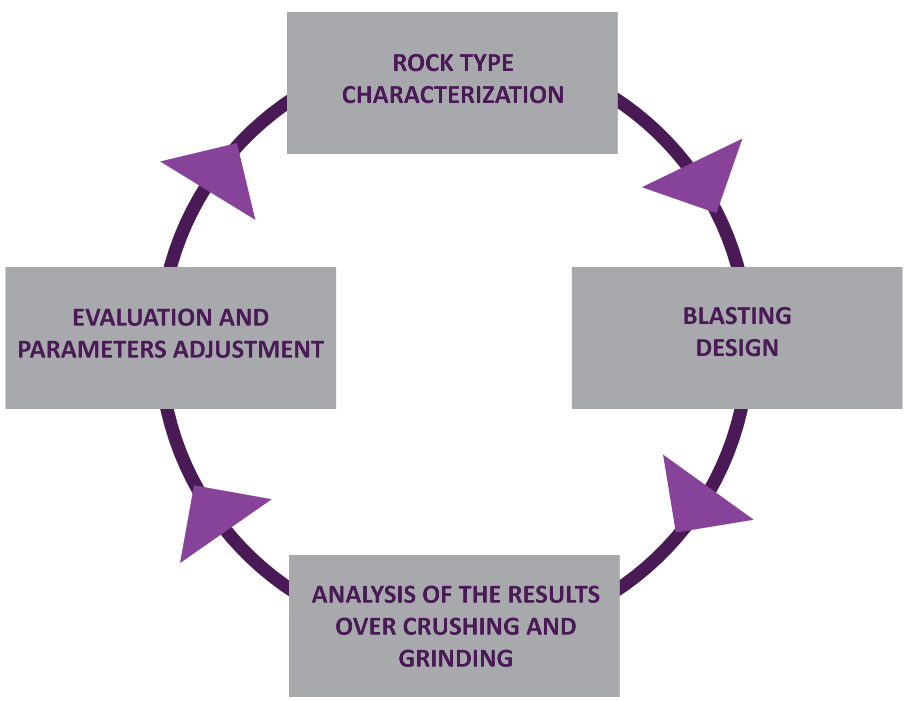
Another example of Mine-to-Mill optimization is the increase of the SAG mill throughput in Porgera mine, Papua New Guinea, where by using this concept studies showed that was possible, by optimizing the blasting design, reaches up to 25% of increase in processing capacity (Grundstrom, Kanchibotla, Jankovich, & Thornton, 2001).

FIGURE 3. MINE TO MILL OPTIMIZATION STEPS



For example, for a rock type with high Work Index it would be possible to obtain better results by increasing the energy consumption in blasting and thus obtaining a smaller particle size for crushing and grinding what would allow to decrease the energy consumption in those stages in order to achieve the target P80. On the other hand, for a rock type with medium or low Work Index, increasing the energy consumption in blasting not necessarily would achieve better results.

FIGURE 4. STEPS OF BLASTING DESIGN OPTIMIZATION



This is because the low Work Index can imply that the extra cost in drilling and blasting could not offset the savings in crushing and grinding. At the same time, studies have shown that over a certain threshold a change in energy in blasting not necessarily imply better results, because the Work Index reaches a plateau, as shown in ***FIGURE 5.*** (Abdel Haffez, 2012; Park, Compan & Kim, en prensa).

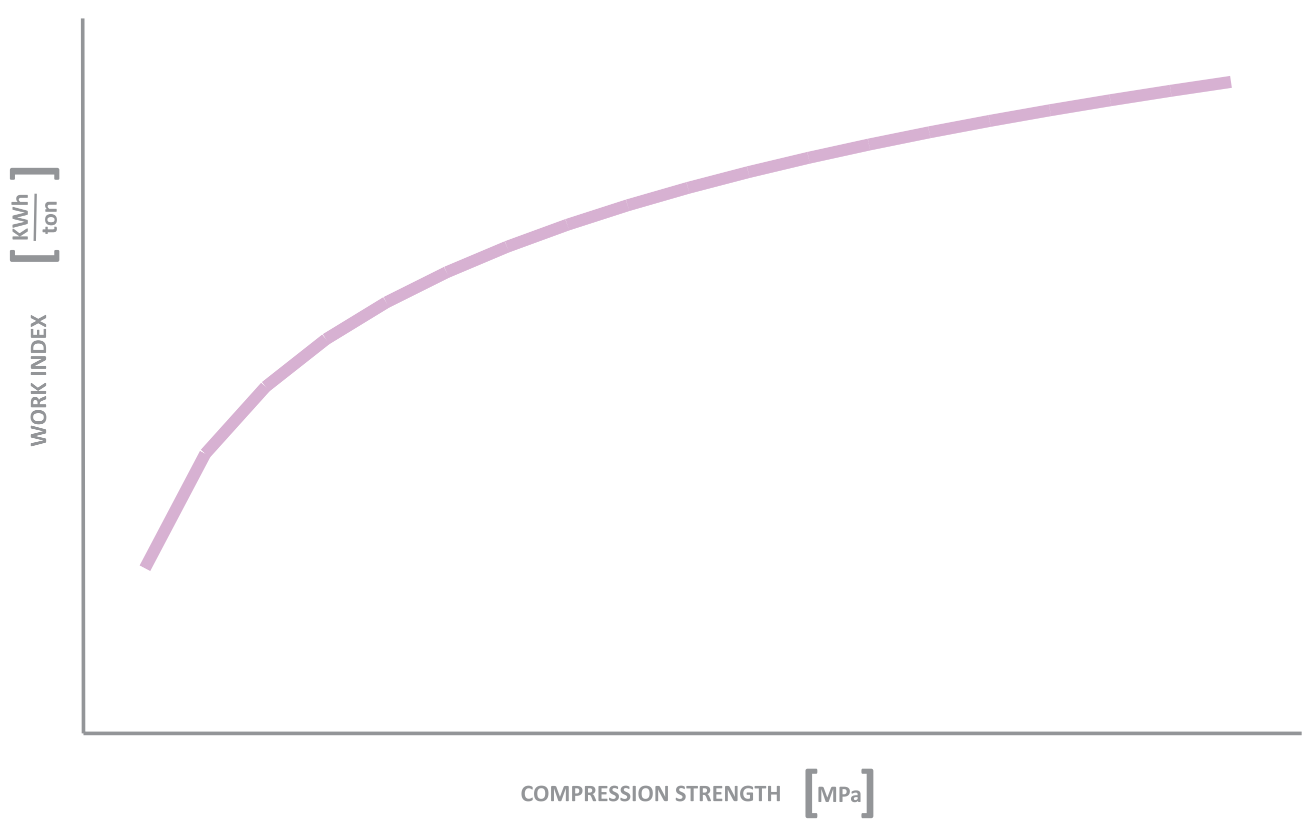
FINAL COMMENTS

Nowadays the mining industry is facing a big challenge: to be capable to decrease operational costs in order to be sustainable over the time. In this regard, the process optimization plays a key role. Although a systemic optimization is ideal, because it guarantees to find an optimal strategy that adds value to the operation, the local optimization can give good results too. When a process is highly complex, when there are bottlenecks or when the processed are independent between them, the local optimization plays a key role. In general terms, when the systemic optimizations turns complex or when is not possible to implement it, the local optimization is the most viable option.

Optimization in mining industry is highly non trivial, because not only the overall system is highly interconnected but also there are several uncertainties associated to the variables involved. This makes necessary the utilization of specialized tools that include, for example, the simulation analysis.

Although people who work in operations aim to improve processes daily, often an external or more holistic view is necessary in order to find not identified opportunities or in order to have a global view of the business. In this regard, in GEM's experience, working with several operations looking for optimal strategies to add value to the business, there are spaces in the mining industry to have savings or value increases up to 5%.

FIGURE 5. WORK INDEX AND COMPRESSION STRENGTH RELATIONSHIP



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