GEOVIA

NEW SOLUTIONS TO MINE-TO-MILL APPROACH

DASSAULT SYSTEMES

INTRODUCTION

The mining industry today is facing a number of new challenges that limit, and may even nullify the effectiveness of the strategies we have relied upon for many years.

Coping with more complex orebodies at lower grades, adapting to new environmental and social regulations/ responsibilities, meeting intensified global demand for commodities within a volatile market – all of these make it essential for mining operations to rethink the way they have traditionally been operated. This includes investigating the use of available methods and novel techniques that can improve short- and long-term mining and processing performance and thereby maximize profitability through best utilization of ore reserves over mine lifespan. One such proven optimization approach is mine-to-mill, which has been used successfully by the minerals industry world-wide for more than 30 years now.

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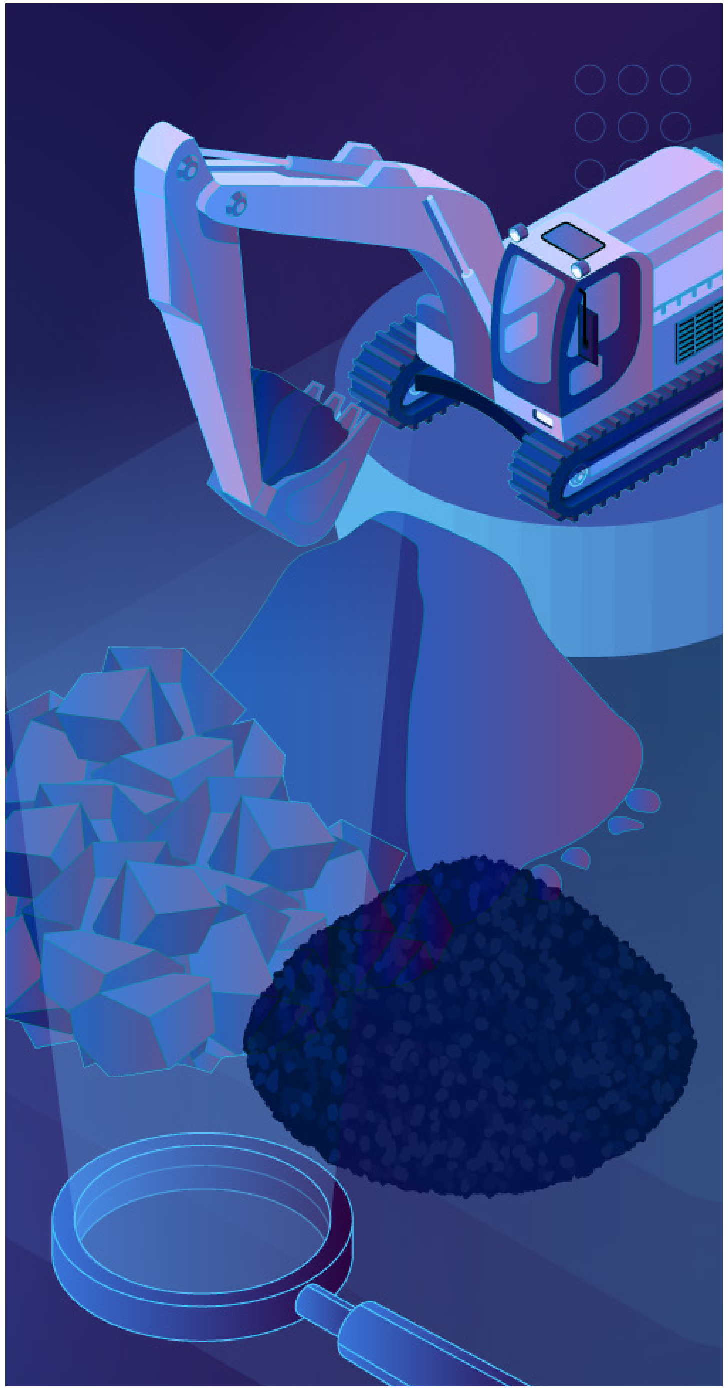
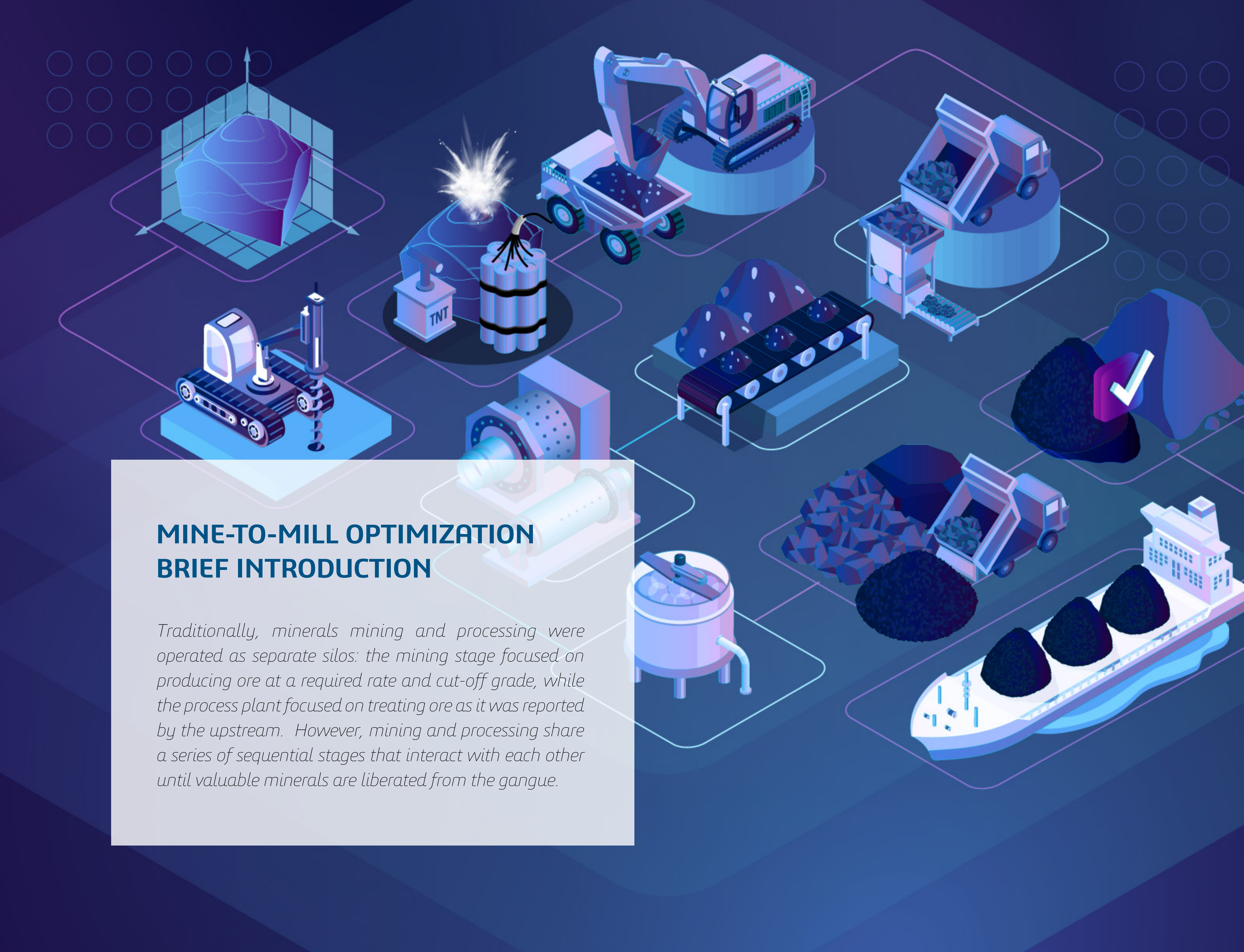
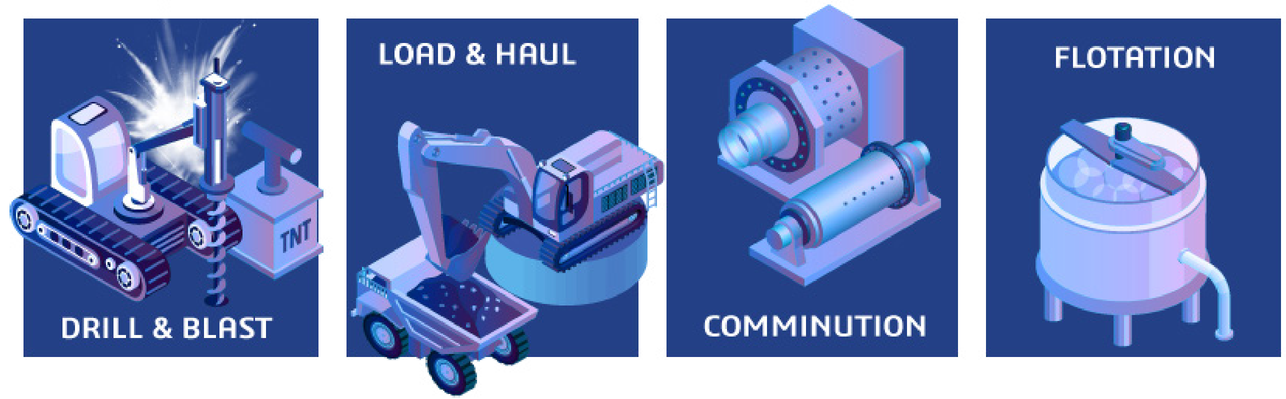




MINE-TO-MILL OPTIMIZATION BRIEF INTRODUCTION

Traditionally, minerals mining and processing were operated as separate silos: the mining stage focused on producing ore at a required rate and cut-off grade, while the process plant focused on treating ore as it was reported by the upstream. However, mining and processing share a series of sequential stages that interact with each other until valuable minerals are liberated from the gangue.

The mine-to-mill approach has been widely implemented in number of mining operations across the globe, with documented productivity gains in the range of 5-20%.



Recognizing this interconnection, the minerals industry began a paradigm shift in the 1990s, moving away from silo-based cost minimization and toward value-driven optimization strategies. This new approach, known as "mine-to-mill", formally links the mining and milling stages in order to unlock opportunities to improve overall productivity and profitability.

Mine-to-mill demands optimal contribution from each stage to achieve the best performance across the value chain, rather than just realizing each silo's distinct objectives. It identifies drill-and-blast as both the first step in comminution and a key leverage point where blast designs can be manipulated to produce more appropriate mill feed size distributions (generally finer in size) for improved downstream performance, specifically grinding capacity.

FOUR CASE STUDY EXAMPLES

Several mine-to-mill optimization projects carried out in the 1990s and 2000s demonstrate how adopting an integrated approach can improve performance records and economic gains. For example:

An Australian gold mine needed to remove a bottleneck at its SAG milling stage and improve the overall performance of its comminution circuit. Through mine-to-mill optimization, the mine tailored the SAG mill's feed size by implementing high-energy blasts relative to standard blasting practice, which resulted in 10% throughput increase.

A gold mine in Papua New Guinea also identified the SAG mill as a production bottleneck. By increasing the blasting powder factor from the standard 0.24 to 0.38 kg/t, the SAG feed P50 reduced from 75 to 35 mm, increasing SAG milling throughput by 15%.

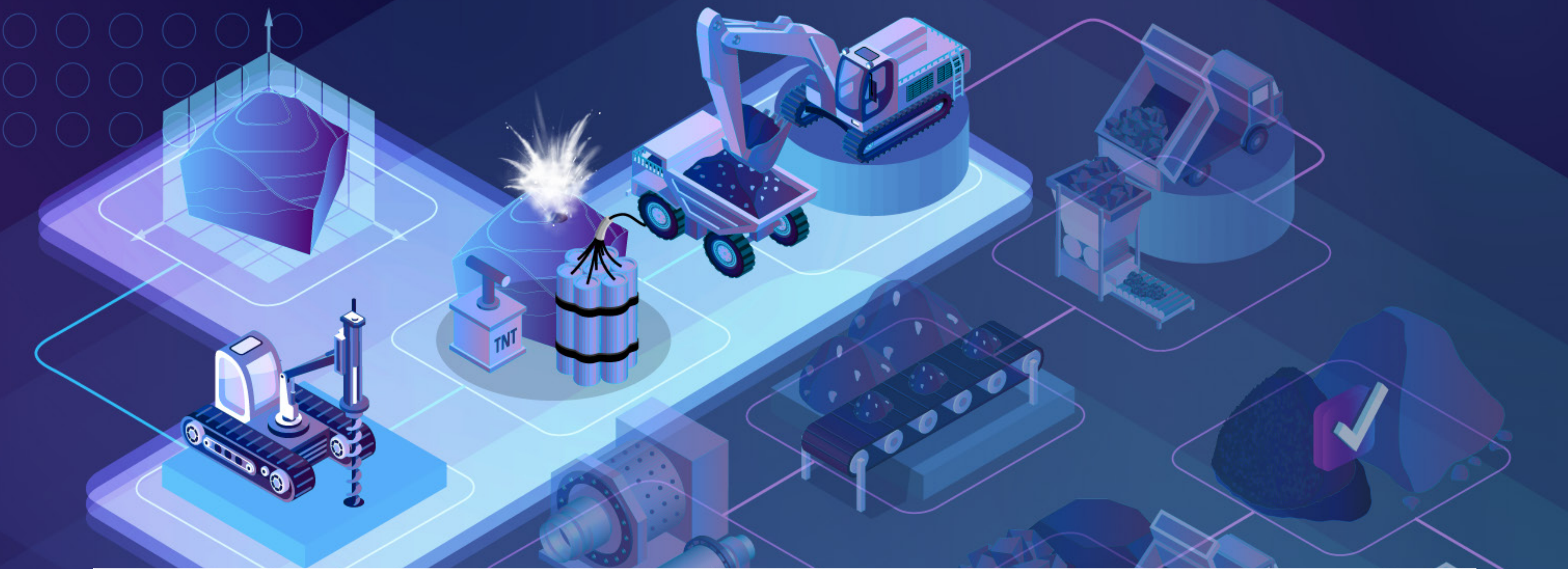
A copper-gold mine in Australia conducted an extensive optimization program that included field surveys, ore characterization, blast fragmentation modeling, comminution modeling, and simulations. Alternative blast designs, in conjunction with a closer crusher gap, improved SAG mill throughput by 12%.

An Australian lead and zinc mine tested whether controlling ore cut-off grade could improve flotation performance. They discovered that removing 30% of "low-value" ore from the mine schedule reduced operating costs while improving recovery of silver, lead and zinc by 5.0%, 5.0%, and 2.0%, respectively.

CONCLUSION

By treating upstream and downstream processes as an integrated whole, mine-to-mill optimization tightens the connection between the mine and the mill, making both ends more productive and therefore more profitable.

The next three articles in this series look at various aspects of mine-to-mill optimization. The fourth suggests how new techniques and technologies can take optimization to the next level and further help mines meet the challenges not just of today but also tomorrow.

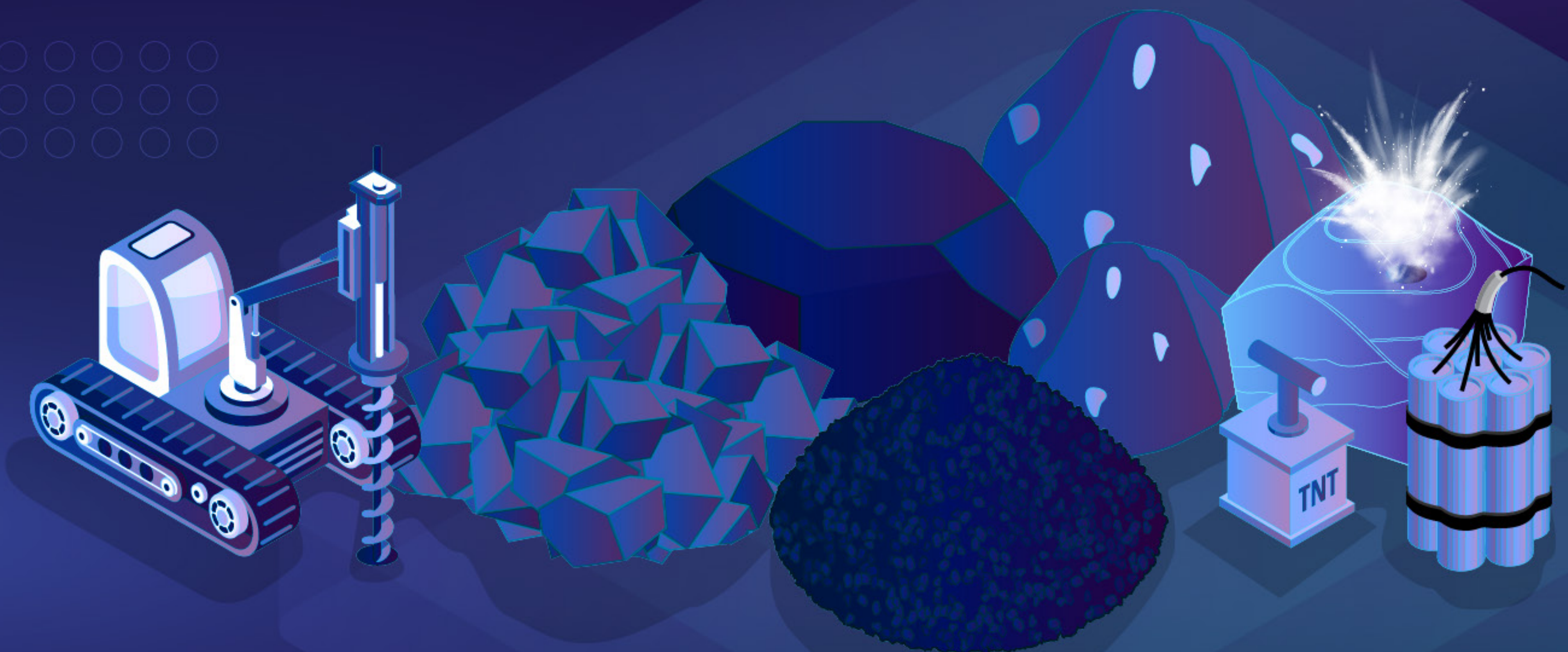


KEY LEVERAGES AND THEIR IMPACT ON DOWNSTREAM KPIS

In mining, the key objective of upstream activities is to remove in-situ rock volumes in sequence and to transfer them as efficiently as possible to different destinations based on their value (i.e. grade/metal content). The key objective of downstream activities is to extract value from the material provided by the upstream. However, the form in which fragmented ore arrives at the plant significantly influences how efficiently –– and profitably –– it is processed through multiple stages of size reduction, classification, and beneficiation until a saleable product is presented to market.

Mine-to-mill aims to improve overall value by establishing links between upstream and downstream activities, beginning with drill-and-blast practice, then transporting ore feed to the process plant. To accomplish this, mine-to-mill generally requires more energy-intensive blast designs (using higher powder factors) than the base case design to increase the amount of fines (below 10mm) in the muckpile. The modified particle size distribution (PSD) then allows for better performance at the coarse grinding stage (i.e. SAG mill) in the form of increased milling throughput.

This article explains how blasting fragmentation (also known as run-of-mine or ROM) affects milling performance.



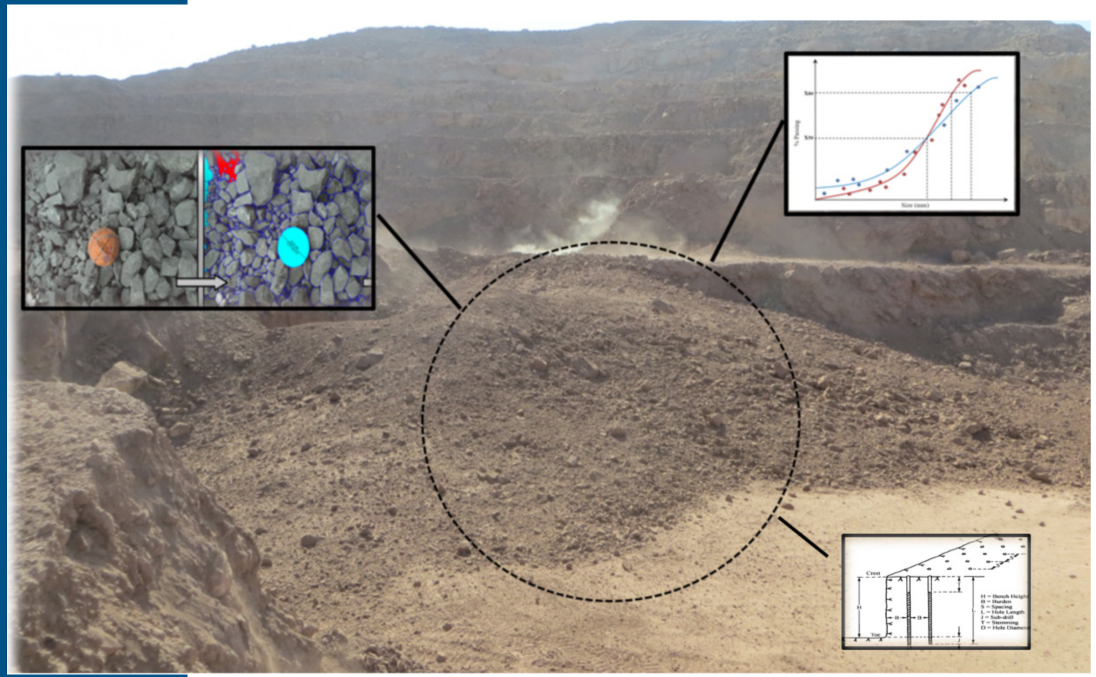
DRILL-AND-BLAST: FIRST STEP IN THE COMMINUTION PROCESS

Rock fragmentation is considered one of the most important aspects of production blasting because it impacts both the costs of drilling and blasting and the efficiency of subsystems, such as loading, hauling, crushing and milling.

Rock fragmentation is influenced by parameters, which can be categorized as:

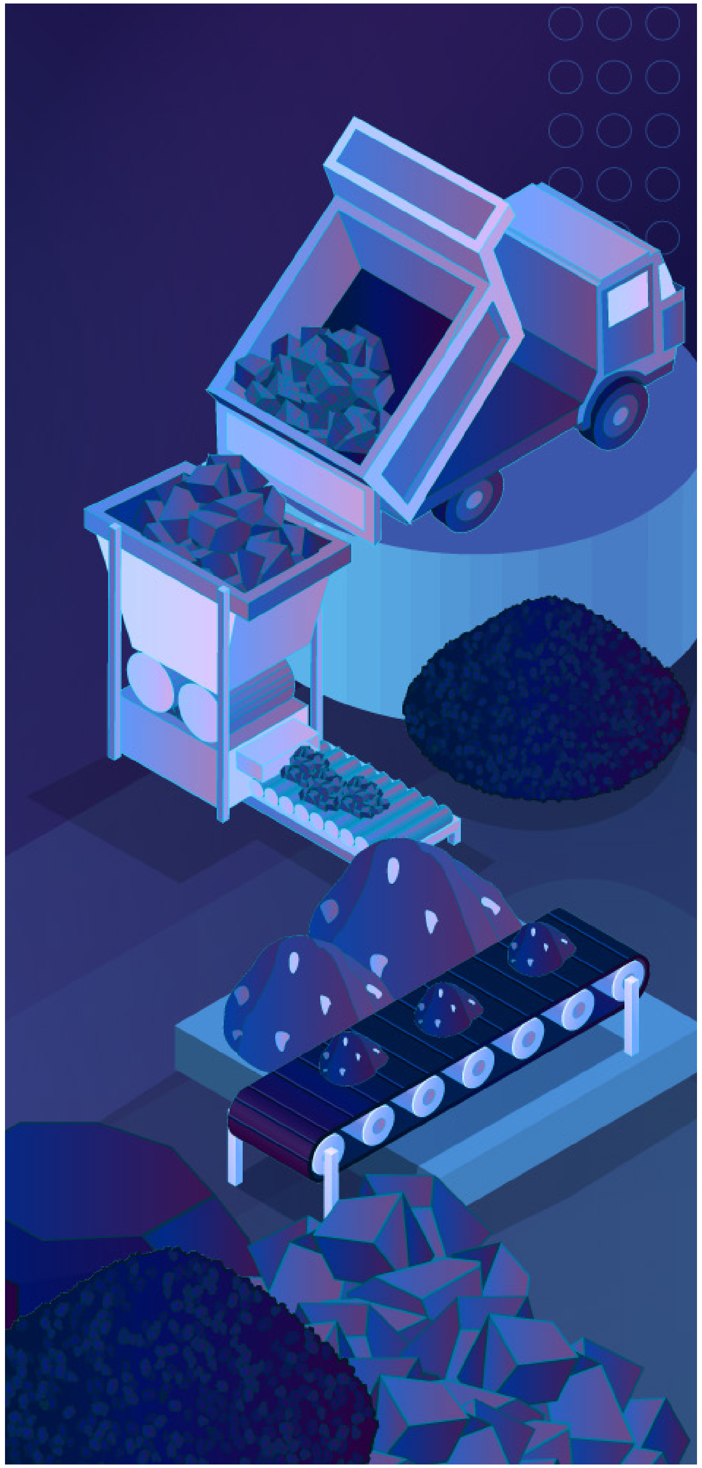
- controllable (e.g. drillhole geometry, sequence and explosive properties), and
- uncontrollable (rock mass properties).

The mismatch between blast design parameters and rock mass properties causes energy dissipation in rock blasting. When the explosive energy releases, apart from useful rock fragmentation and displacement, a considerable portion of that explosive energy is wasted in the form of undesirable side effects, such as ground vibration, noise, flyrock, over-breaks, ore loss, and dilution. However, a well-designed blast can result in "good" fragmentation and fewer side effects.



Typically, blasting is considered "good" when drill-and-blast costs are minimal and it fragments rock into particles that are fine enough and loose enough to be easily loaded and hauled away to the process plant. With the mine-to-mill approach, on the other hand, the degree of blast fragmentation is driven by feed-size requirements defined by the process plant. While producing the finer fragmentation commonly results in higher drill-and-blast costs, however, this increase can be justified in light of that fact that ore comminution is the most energy-intensive process in almost all mines. **Therefore, a quality ore feed specifically tailored in size and metal content to meet milling requirements not only improves process performance in short-term, but also assists with significantly increased overall value over life-of-mine.**

The crushing and grinding process is more or less efficient depending on the ROM size distribution, particularly for autogenous (AG) and semi-autogenous (SAG) milling, because a significant proportion of the grinding media (in AG mills, all of it) is comprised of ore feed. The more closely ore feed size distributions match downstream requirements, the more efficient, and therefore more profitable the processing will be.



HOW BLASTING IMPACTS COMMINUTION

Crushing and grinding are comminution stages through which ROM size distribution is reduced to a certain size range within which most valuable minerals are liberated for later beneficiation stages, e.g. flotation. **Since blasting is the first step in the process of breaking rock down to a specific size fraction, it has a significant effect on subsequent breakage processes by comminution machines.**

Mine-to-mill involves increasing the amount of breakage achieved in blasting to decrease the amount of grinding effort required at the AG/SAG milling stage. This moves a notable proportion of size-reduction load back to the mine, where application of energy is more cost-efficient than at the mill. It is worth to be noted that, in general, AG mill performance is better with coarser feed because it requires large enough rock particles to act as grinding media and break smaller rocks.

At a constant ore feed hardness, any change in the feed size will affect the breakage characteristics of the SAG mill. That is, for a finer feed size, a decrease of the charge volume and therefore the power draw is expectable – either because relatively larger proportions of ore feed already meet (free grind material) or that in a shorter time will satisfy the size requirement for being discharged – which results in a higher throughput. In other words, it is the charge that changes owing to a different feed size.

However, it is important to remember that while conducting more intense blasting will generally increase the SAG mill throughput, it will also have an impact on the next stages, ball milling circuit performance and recovery, and this impact should be understood and accounted for.

Conclusion

Tailoring blast fragmentation by performing more intense blasts (~2-3 times) generates significant differences in the fines and intermediate size fractions relative to a standard blasting practice. This strategy often helps unlocking additional milling capacity, and ultimately helps better align production objectives along the entire value chain.

At the same time, any changes in feed size should be based on a proper understanding of the impact on the following stages and should consider equipment design and operational constraints. There are always risks to changing any practice, and with mine-to-mill in particular, there are risks to mitigate and competing priorities to balance.

HIGH ENERGY BLASTING: EXPECTED RISKS AND OFFSETS

In this article, you will learn about the expected risks of adopting mine-to-mill optimization strategies and the offsets available to balance installed power between the SAG and ball milling units to take advantage of potential mine-to-mill gains.

As we discussed in our last article, blast design can provide the process plant with feed size distributions (PSD) that significantly improve process performance. In addition, a finer fragmentation generated by performing relatively high-energy blasts, also makes it easier to excavate and transport material within the mine. Therefore, changing PSD in the upstream can determine the economics of many mining projects as it impacts the value chain.

At the same time, however, it can be difficult to control high-energy blasting outcomes, which increases the risk of side effects, such as backbreak, ground vibration, air-blast, and flyrock. The approach turns blast movement control into a challenge, which can also result in ore loss and dilution, which can negatively impact process recovery and hence lead to a significant loss in the overall value over time.

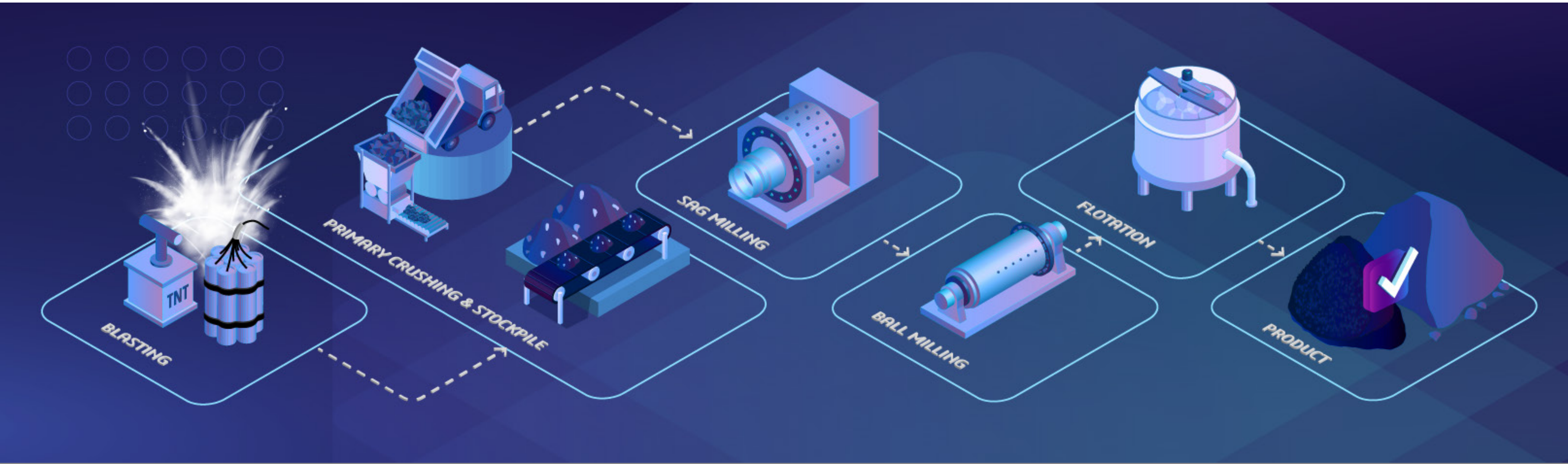
In this article, in addition to a review of expected risks and offsets, we specifically discuss how ore loss, ore dilution and loss of recovery might cause diminishing long-term profit, and nullify effectiveness of optimization strategies adopted in the upstream.

IMPORTANCE OF POWER BALANCE BETWEEN SAG AND BALL MILLING STAGES

Before implementing the mine-to-mill approach, operations must understand the impact of applied changes on the process and how it may influence interaction between different units of process, including crushing, coarse grinding, fine grinding, and flotation. It is important to note that removing a bottleneck without respecting the next stage operational constraints may result in building a new bottleneck, which would effectively nullify upstream optimization practices. In this article, we consider a SABC circuit (SAG-Ball Mill-Secondary Crusher) to briefly explain how a mismatch between different units may become problematic.

At the SAG milling stage, one of the main operational challenges imposed by feed size and competence variability is the challenge of maintaining a steady load due to changes in SAG mill comminution characteristics and discharge rate. In SABC circuits (depending on operational constraints of a process plant), changes associated with feed size and its properties may induce imbalance of installed power between the SAG and ball milling units. The imbalance can result in the circuit shifting from SAG to ball mill limitation – increasing the risk of underutilization of available power and hence throughput limit.

Coarser and harder particles tend to accumulate and dominate the mill content, limiting the throughput, while softer and smaller particles (smaller than the SAG screen size) empty the mill quickly, increasing risk of liner damage by the steel media.

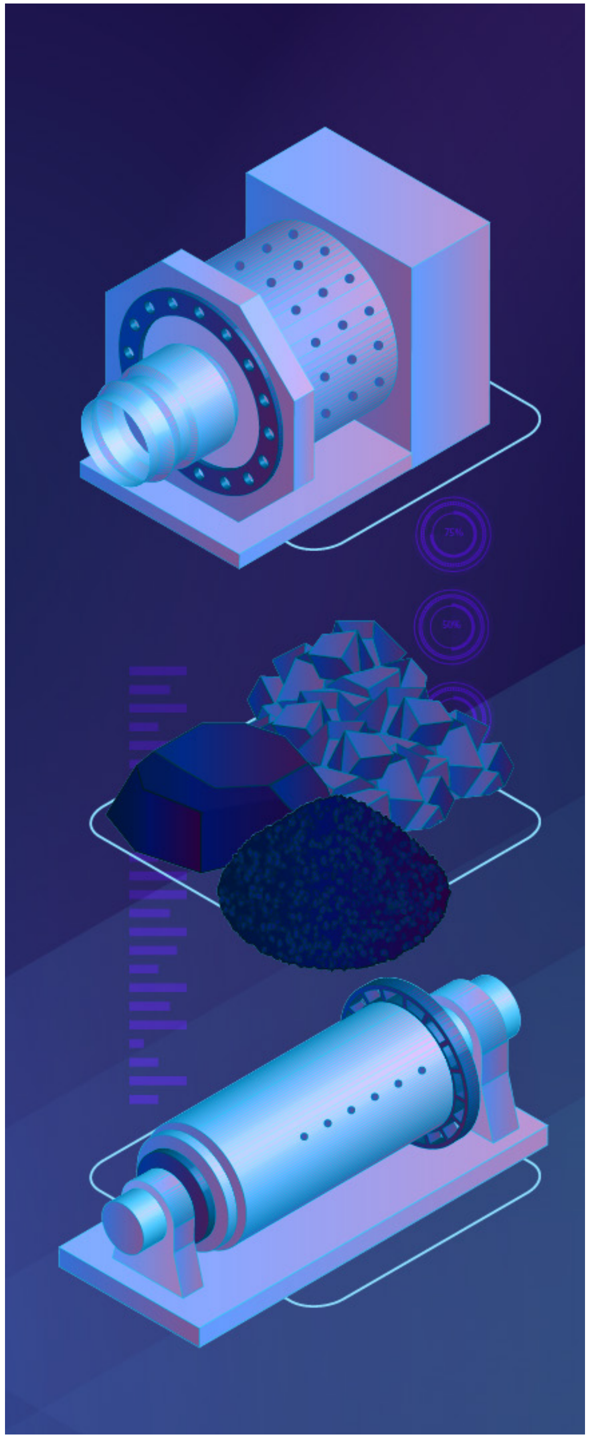


For a competent ore domain, intense blasting can help generate a finer feed, offsetting difficulty in grinding a harder ore type at the SAG milling stage – resulting in a slightly a coarser 'transfer size' (or coarser SAG mill product) being transferred to the ball milling stage at an increased rate – which can limit capacity at the ball milling stage. For a soft ore type, a feed with a high proportion of soft particles in SABC grinding circuits can also limit throughput at the ball milling stage. Because in both cases, an increased discharge rate at the SAG milling stage (often followed by a relatively coarser product) may overload ball mills/ hydrocylone circuit, resulting in increased pressure on recirculating load (~>300%), which often restricts the capacity or "hydrocylones overflow rate". Another barely discussed scenario might be when crushed SAG pebbles (which are generally comprised of harder material) are diverted to the ball milling stage with the aim of improving SAG mill throughput.

As a result, ball mills will process material which may be significantly harder than the "initial" circuit feed. In all these scenarios, the ball milling stage may become "the next" operational bottleneck within the value chain. **Therefore, not being able to harmonize the interaction between SAG and ball milling units after applying changes in the feed size or in response to change of ore properties, can result in not taking advantage of finer fragmentation from optimized blasting practices.**

There are various operational strategies operations may adopt to mitigate the risk of shifting bottleneck from SAG mill to ball mills. One such lever is to increase hydrocyclone cut-size (overflow P80) to reduce circulating load – however, this must be coupled with a review of possible negative impact on flotation as the coarser P80 might have a negative impact on recovery. It is worth noting that in many cases, it is required to apply several strategies in addition to enlarging P80, which might include changing the pebble port size, SAG discharge screen aperture (transfer size), etc.

To maintain long-term benefits, domain-based blasting strategies should be established for tailoring fragmentation in favor of downstream feed requirements. This would help optimize the process plant performance through balancing SAG and ball mills priorities and support increased SAG throughput.

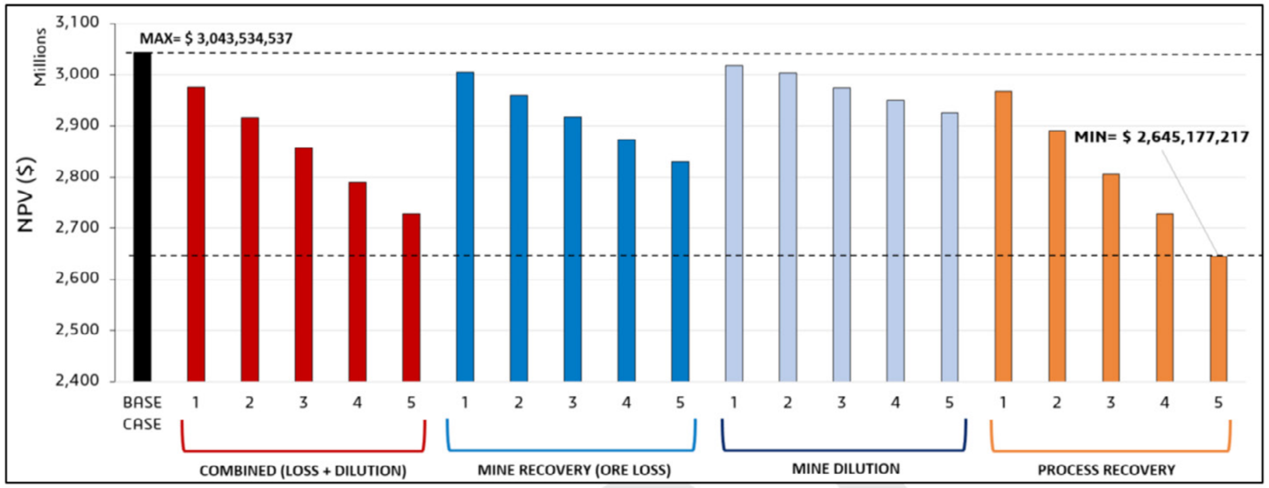


ORE LOSS, DILUTION AND PROCESS RECOVERY

High-energy blasting requires good rock mass characterization for grade boundaries and advanced understanding of blast movement or it can result in remarkable financial losses in form of ore losses, dilution and poor recovery at the flotation stage.

Ore dilution occurs when waste/ lower-value material is sent to the process plant – diluting ROM head grade leading to both decreased metal yield (recovery) and increased cost of grinding. Ore loss occurs when valuable mineral is sent to the waste dump, decreasing ore-reserve utilization and causing significant loss of value over life-of-mine. The graph below illustrates how ore dilution and ore loss could potentially diminish or improve NPV of a copper mine.

As it is shown in the graph, the metal yield and recovery has a significant influence on NPV. The results suggest the importance of establishing grade control strategies at upstream and downstream stages and quantifying value at specific time periods to evaluate their effectiveness. **A sustainable grade control strategy requires well-developed pre-blast and post-blast strategies, including measurement, modelling, optimization, and value quantification.**



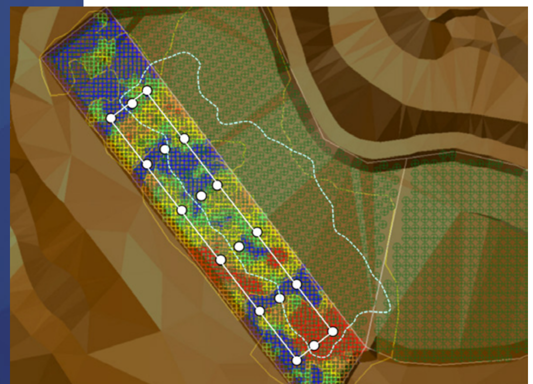
CONCLUSION

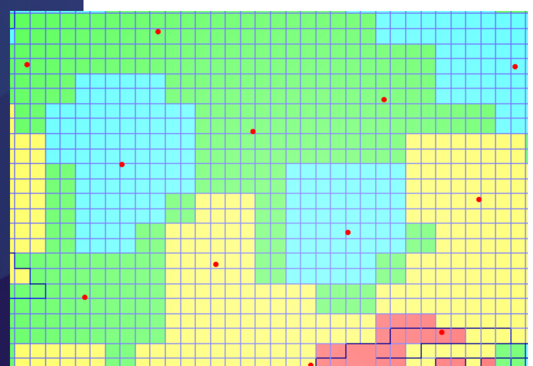
Adopting a mine-to-mill optimization approach can improve the productivity of the entire value chain, if associated risks and offsets are reviewed and understood. It is necessary to establish built-in strategies at the blast design stage and through the process plant and between its units to control change of PSD side effects and effectively manage ore variability to ensure optimal performance (throughput and recovery).

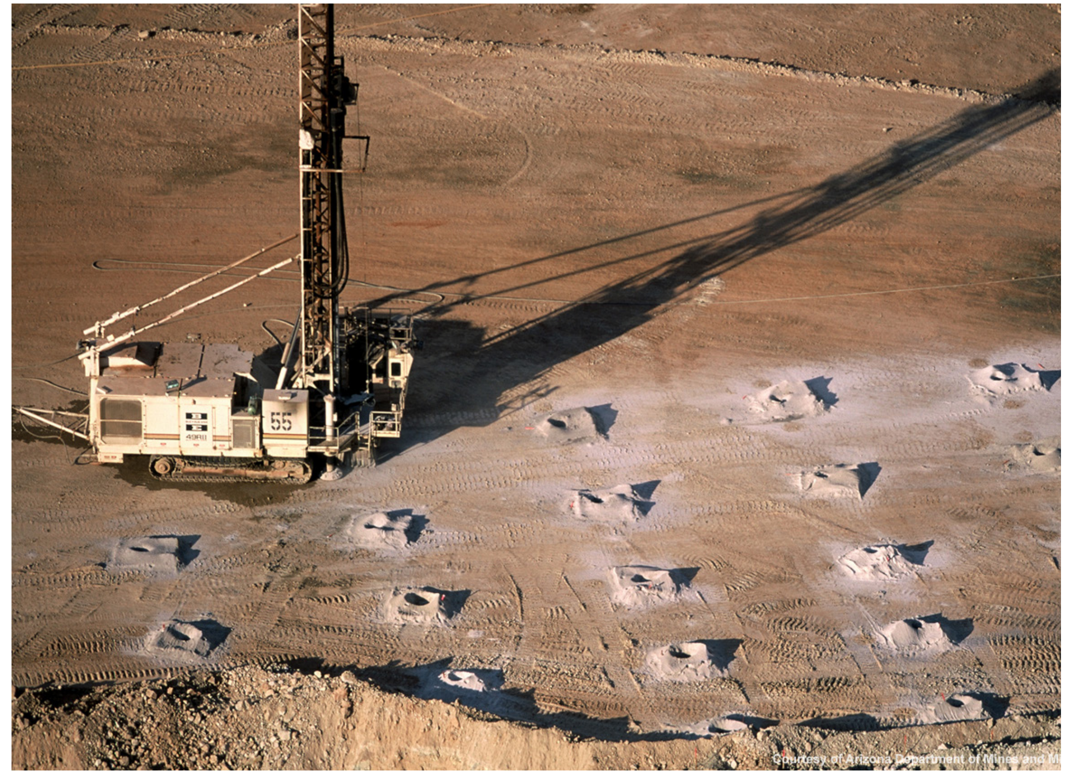
OPPORTUNITIES TO GAIN MORE FROM MINE-TO-MILL

In this article, we review some of the techniques and technologies that can help harmonize upstream and downstream activities and take the mine-to-mill approach to the next level.

Making the best use of ore reserves over life-of-mine (LOM) is becoming more important as mines today come to grips with a multitude of challenges that were not even on the horizon a decade or so ago. These include, but are certainly not limited to, coping with more complex orebodies at lower grades, adapting to changing environmental and social regulations and responsibilities, and meeting rising global demand for commodities within a volatile market. Fortunately, there are a number of novel techniques and new technologies that were not on the horizon a decade or so ago that can help improve short- and long-term mining and processing performance.







MEASUREMENT WHILE DRILLING (MWD)

Rock mass properties significantly impact the efficiency of drill and blast operations. Compared to laboratory-based characterisation techniques, Measurement While Drilling (MWD) technology, takes less time and is relatively less expensive, while allowing mines to obtain and measure real-time data on the rock mass in the process of blasthole drilling.

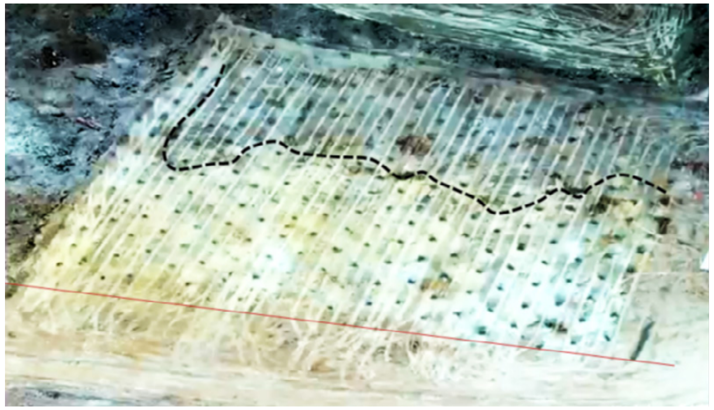
As a system, MWD monitors a range of parameters that reveal rock mass characteristics, including air pressure, feed pressure, percussion pressure, rotation speed, drilling rate, drilling depth, and torque. *With this real-time data in hand, drill and blast engineers can respond quickly to changes in the rock mass and improve the reliability of their blast designs by tailoring blast energy for each individual blasthole.*

BLAST MOVEMENT MEASUREMENT & ORE LOSS REDUCTION

Rock mass displacement caused by blasting alters the coordinates of grade boundaries, resulting in ore loss and dilution, both of which impose significant financial losses.

Ore loss occurs when valuable material is misclassified as waste and sent to the waste dumps, which significantly reduces orebody utilisation and hence diminishes the overall value over mine lifespan. Ore dilution occurs when waste material is misdirected to the processing plant, where it degrades feed quality, lessens recovery, and results in huge losses in comminution energy by causing the process plant to grind uneconomical fractions of feed ores. Therefore, it can potentially impact operational and economical aspects of the whole value chain.

Blast Movement Monitor (BMM) is a technology developed and patented by the JKMRC, University of Queensland, used for measuring displacement directions. It consists of electronic transmitters placed within the blast volume before blasting which are then located after the blast with a special receiver. BMM technology provides 3D movement vectors in a reasonable time before start of loading.

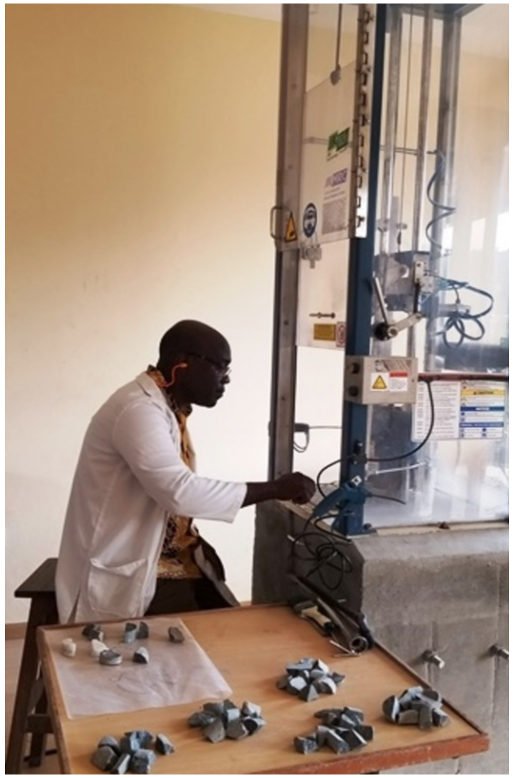


BEFORE BLASTING

Julius Mine Site, Western Australia

AFTER BLASTING

Julius Mine Site, Western Australia

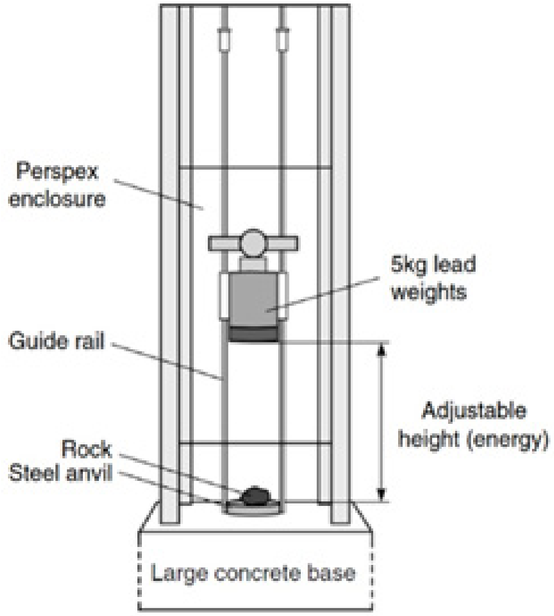


ORE COMPETENCE VARIABILITY MEASUREMENT

Despite the fact that breakage characteristics of ores vary, most of the current ore testing methods are average-based and therefore do not capture the variability with the sample. This can lead to unpredicted variation in process performance, which can cause unstable performance of grinding circuits, inconsistent fineness of grind, operation and optimisation difficulties, reduction in recovery, and reduction in classification efficiency.

Considering the impact of ore variability on process performance, it would be beneficial if mine-to-mill practices convert into ore characterisation techniques which are specifically capable of measuring and describing the extent of ore competence variability.

This potentially can enable minerals industry to better assess risks associated with equipment selection, process design, and optimisation strategies (Read More HERE).



ORE PRE-CONCENTRATION

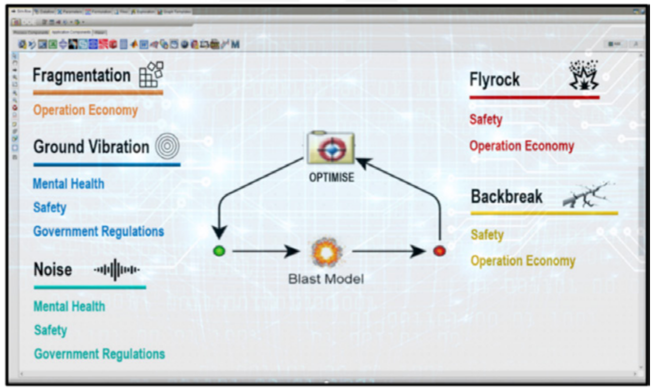
Pre-concentration in mining attempts to improve ore-feed quality by removing low-value gangue material prior to the comminution process, which can potentially strategy reduce the energy input per unit of the final product.

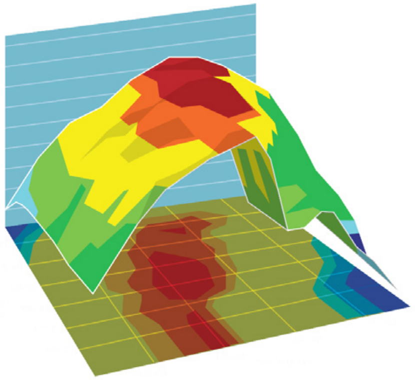
Pre-concentration requires a suite of well-established techniques and technologies being utilized to exploit differences in physical and chemical properties of an ore to separate valuable minerals from gangue. *Thus, depending on ore characteristics, a technique based on size, gravity, conductivity, competence, magnetic susceptibility, thermal reactivity etc., can assist with feed upgrade prior to energy-intensive size reduction stages.* With recent advancements in the pre-concentration area, the approach should be considered in any mine-to-mill practice as a lever to improve or 'unlock' additional value (Read More HERE).

SCENARIO-BASED SIMULATION

In today's computer-aided product development and manufacturing environment, designers and engineers are using a wide range of software tools to design and simulate their products. In mining, constraints-based simulation can improve understanding of the interaction between key stages across the value chain in a quantitative manner, while at the same time accounting for operational constraints and bottlenecks. This helps mines make informed-decisions and develop optimal strategies for improving long- and short-term mining and processing performance, thereby mitigating risks associated with CAPEX and OPEX.

For example, mine-to-mill practice requires optimising blast fragmentation in favour of milling, which may require testing a combination of several input variables (blasthole diameter, burden, spacing, explosives properties, etc.), each of which may vary within a range. Technologies such as Dassault Systemes' SIMULIA can reliably optimise blast design for a specific outcome e.g. degree of fragmentation, in a reasonable time (e.g. ~ 1000 scenarios per minute) by combining cross-disciplinary models and applications together in a simulation process flow, automating their execution, and identifying the optimal design parameters subject to required constraints (Read More HERE).





CONCLUSION

Minerals industry can now access a variety of techniques and technologies to improve short- and long-term mining and processing performance. In turn, these techniques and technologies can help mines harmonize their upstream and downstream activities and make the mine-to-mill approach even more successful.

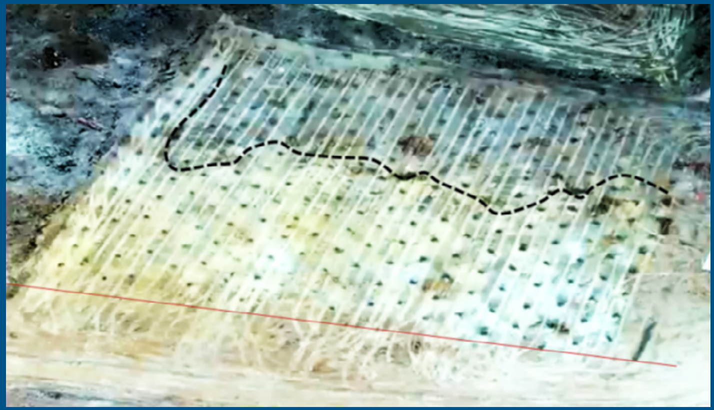
GRADE CONTROL AS A STRATEGIC LEVER IN MINE-TO-MILL OPTIMIZATION

We are now concluding our mine-to-mill technical series by focusing on grade control as a critical strategy that should be considered as part of future mine-to-mill practices, and suggest a solution to tackle ore loss and ore dilution induced by blasting.

THE CHALLENGE OF ORE LOSS AND DILUTION INDUCED BY BLASTING

Rock mass displacement caused by blasting alters the coordinates of grade boundaries, resulting in ore loss and ore dilution.

Ore loss occurs when valuable material is misclassified as waste and sent to the waste dumps, diminishing the value of the mine over its lifespan. Ore dilution occurs when waste material is misdirected to the processing plant, where it degrades feed quality, lessens recovery, and wastes comminution energy by causing the process plant to grind uneconomical fractions of feed ores.



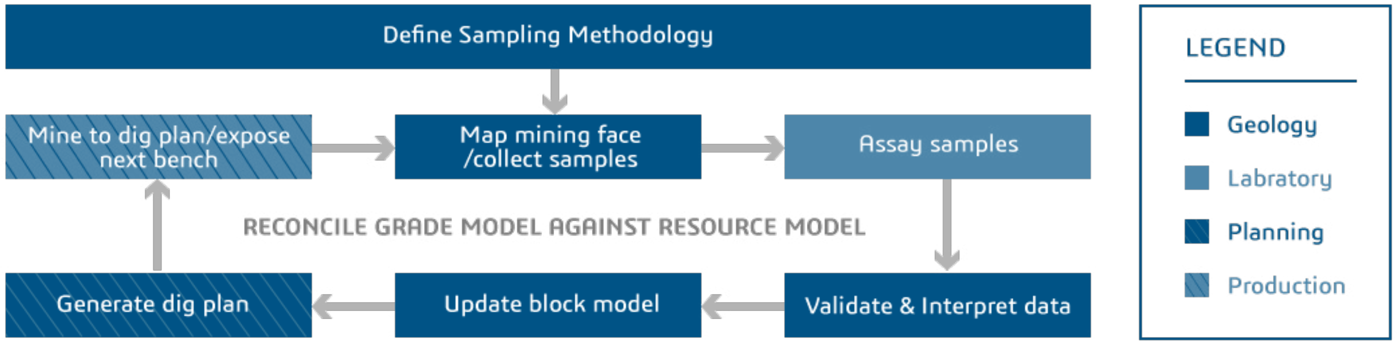
BEFORE BLASTING *Julius Mine Site, Western Australia*

AFTER BLASTING *Julius Mine Site, Western Australia*

KEY REQUIREMENTS FOR MINIMIZING RISK OF BLAST-INDUCED ORE LOSS & DILUTION

Ensuring that the processes that define grade control are efficient and repeatable is critical to driving profitability.

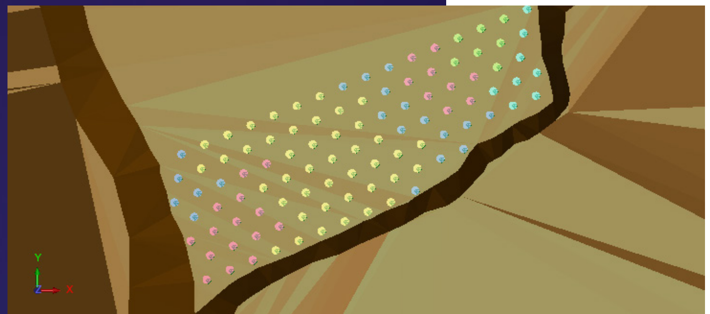
Grade-control capabilities are an integral part of GEOVIA's Surpac™, which means we can help you implement new and improved grade control procedures at any stage in the lifecycle of a mine, and develop strategies for dealing with ore loss and dilution induced by blasting.

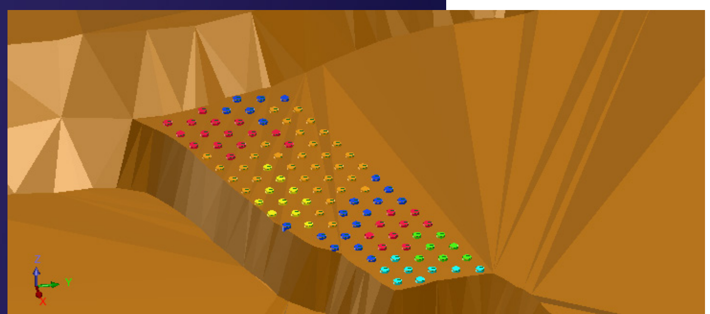


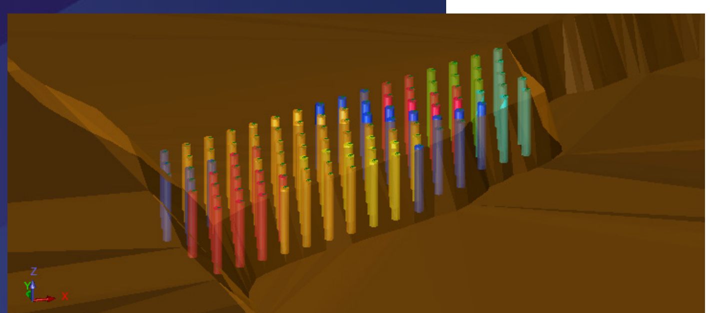
In the blasting realm, a sustainable grade-control strategy requires well-developed pre-blast and post-blast strategies, including measurement, modelling, optimisation, and value quantification.

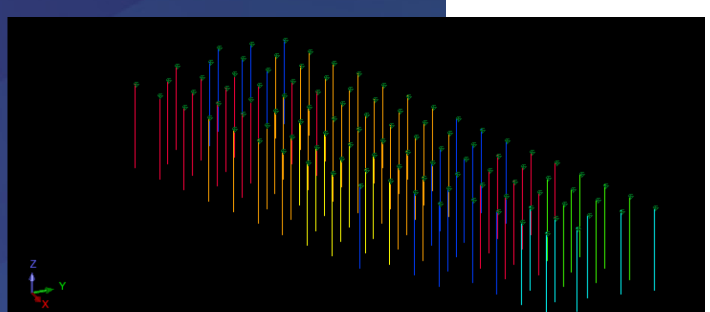
The extent to which a design would be capable of delivering desired outputs in different geological domains depends on how well the heterogeneous nature of ore domains is captured by a model. To efficiently address a complex problem such as ore loss and dilution, a solution should be sophisticated enough to allow engineers and specialists to continuously improve their understanding and their designs based on measurements produced in a timely and integrated manner.

Strategic assessment and control of ore loss, dilution and recovery is an engineering solution specifically developed for continuous improvement and long-term gains. The solution includes three key stages of mapping data and 3D visualisation through block- and grade-control models, mass simulation and optimisation, and strategic value quantification.









STAGE 1: MEASURE & VISUALISE

Stage 1 deals with resource modelling and field measurements – *i.e. blasthole assays, bench-scale grade control model, material classification, Measure While Drilling (MWD) and Blast Movement Monitor (BMM) data*, as well as blast-design parameters.

Any type of data collected can be integrated and used for 3D visualisation, design improvement, and analysis. The input data can express drilling penetration rate, grade, geo-mechanical indices (UCS, Young Modulus, Joint Density, etc.) or geo-metallurgical including grade, mineralogy, ore hardness (BWi), ore competence (SPI or Axb).

- *This allows blast engineers to visualise pre-blast grade boundaries within the block and their post-blast coordinates after movement, and to evaluate heaving performance.*

STAGE 2: SIMULATE & OPTIMISE

Stage 2 produces constraint-based scenarios through a massive simulation of combinations of variables in light of grade-control model and field information. Analysis of these scenarios identifies optimal blast-design alternatives for different geological domains while respecting design and operational limits.

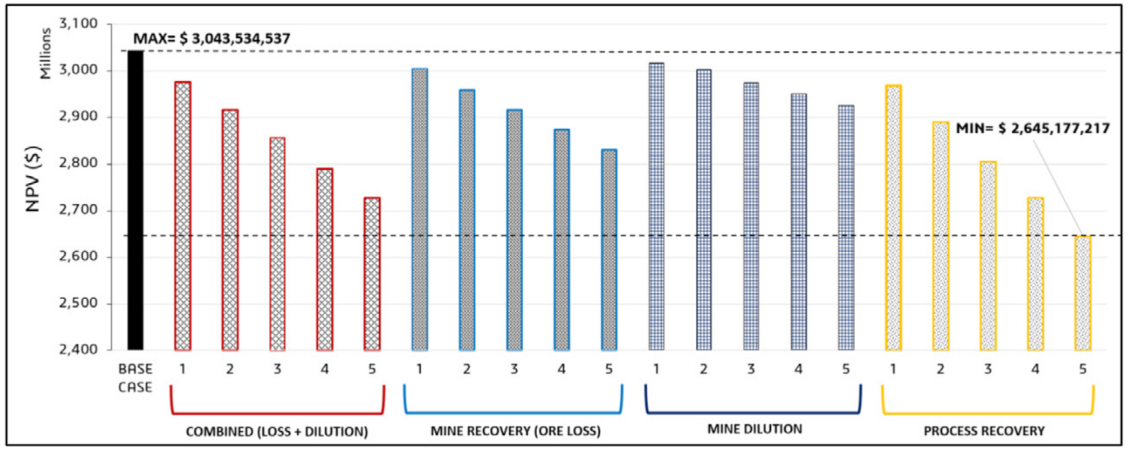
- *This stage allows specialists to establish expert-based strategies by comparing pros and cons of best design alternatives in a reasonable timeframe (~1000 scenario per minute).*

STAGE 3: QUANTIFY VALUE & MAINTAIN

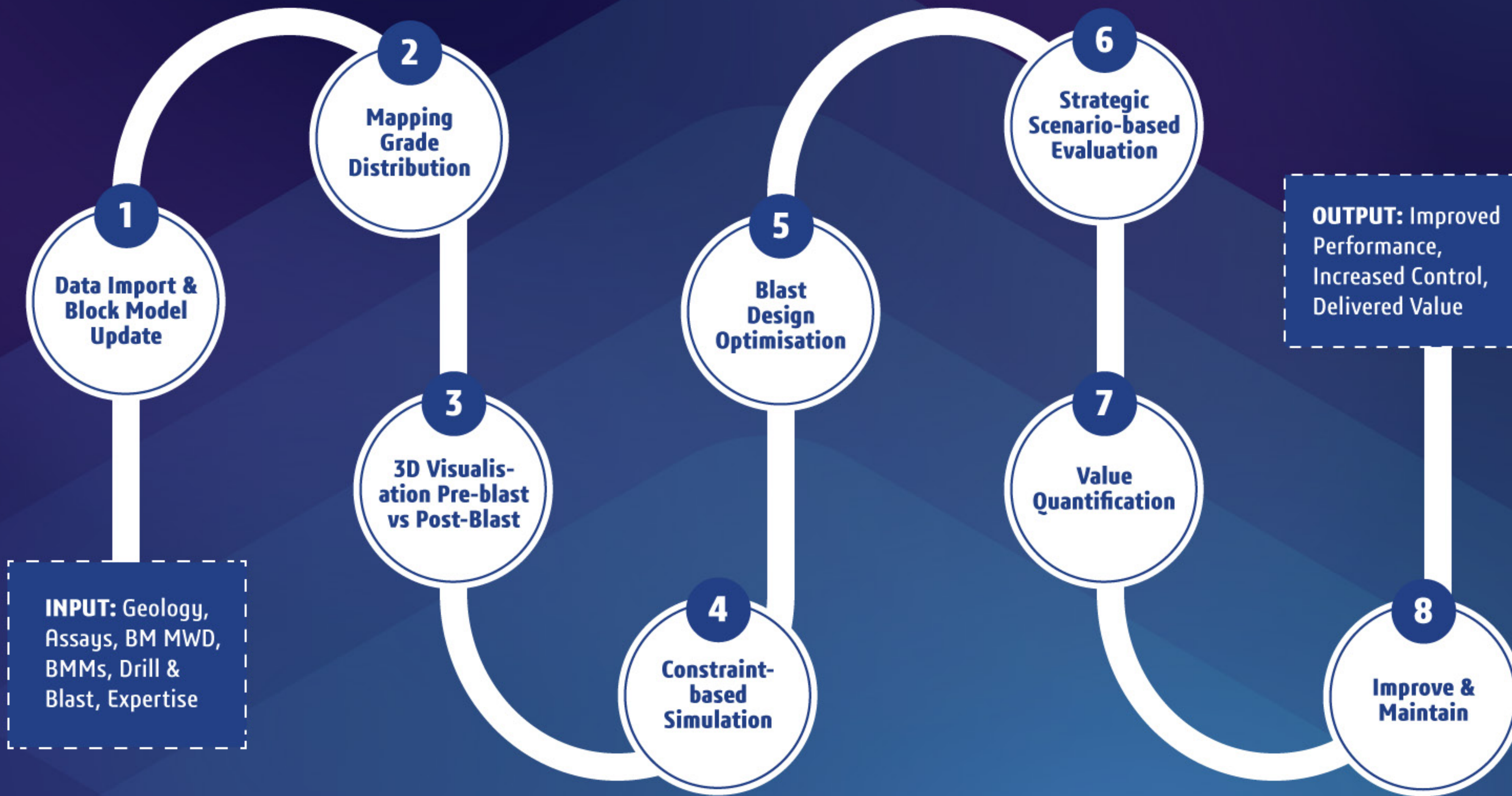
Stage 3 is the strategic assessment of potential gains and losses from grade-control strategies adopted in the upstream.

- *This stage allows specialists to quantify the effect of simulated strategies expressed in terms of Net Present Value (NPV).*

The 'strategic scenario-based analysis' below implies how ore dilution and ore loss could potentially diminish or improve NPV of a copper mine.



As it is shown, the metal yield and recovery significantly impacts NPV. The result highlights the importance of being able to evaluate the impact of grade control strategies at upstream and downstream stages at a strategic level and monitor their impact on the overall value over LOM.



CONCLUSION

The solution developed at Dassault Systèmes uses globally-trusted, multi-functional software packages that are also capable of dealing with blast-induced ore loss/dilution problems. The workflow below illustrates key steps critical for mitigating risks associated with poor blasting – i.e. ore loss/dilution. The step-by-step workflow summarises the solution and details how such technologies help address ore loss and dilution problems pragmatically for sustainable gains.

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