Bulk Ore Sorting

Whitepaper

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Declining ore grades

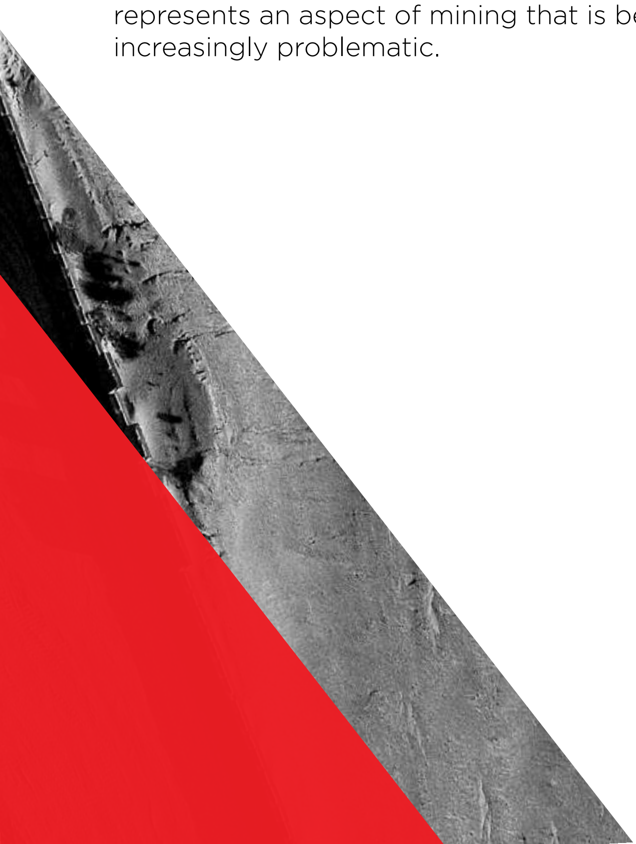
Grade is critical to profitability in a mining operation but it is a naturally occurring characteristic that is beyond the control of the miner. Between 2003 and 2013, it is estimated that the average grade at global copper mines decreased by 25 percent (Calvo, Mudd, Valero, & Valero, 2016). As global grades decline, and new high-grade discoveries become increasingly rare, operating mines and development projects are facing mounting pressure to materially improve the efficiency of mining systems.

Along with declining profitability, another bi-product of declining grade is a vast and increasing volume of waste produced from mining and processing. It is estimated that annual mine waste and tailings production ranges from 4.5 to 6.3 billion tonnes per year (Mudd & Boger, 2013). All things equal, as grades decline, each unit of metal production represents a larger tailings storage burden. Tailings management, as demonstrated by notable recent disasters, represents an aspect of mining that is becoming increasingly problematic.

Mining, which has always struggled with its image, risks losing its social licence to operate if it cannot improve in this area.

Lower grades also correspond to higher consumption of electricity and water from mining operations. An average gold mine uses between 25 and 150kWh of electricity per tonne of ore processed (Calvo, Mudd, Valero, & Valero, 2016). Similarly, a conventional copper processing plant uses between 0.7 and 1.0m^3 of water per tonne of ore (Suvio, Kotiranta, Kauppi, & Jansson, 2017). Companies are continuously looking for methods to improve efficiency and water recycling to reduce these figures, but if more tonnes of feed are required per unit of metal production, overall consumption will continue to increase.

Mines that have operated effectively for years or decades are facing an urgent need to improve profitability or else face the prospect of mine closure. Any resolution to this problem needs to deliver a combination of improved revenue and decreased cost without introducing excessive complexity, and all while maintaining or improving upon the social and environmental performance of the mine and its owner. Where applied properly, bulk ore sorting systems represent an opportunity for miners to simultaneously achieve these outcomes.



Ore sorting

Sorting systems fall into two general categories; particle sorting and bulk ore sorting.

Particle sorting evaluates rocks or particles individually and decides if it is valuable and should be retained for processing or rejected. To do this, ore must be crushed, sized and scattered evenly in a single layer over a wide conveyor belt above or below a mounted sensor. Pneumatic blowers or paddles are then used to redirect ore to the appropriate product stream. The advantage is that an accurate selection of ore versus waste is possible. However, throughput is limited to several hundred tonnes per hour and the systems suffer from high capital and operating cost impacts, as well as being unable to accommodate fine material (<10 mm).

Bulk ore sorting evaluates the contained metal and associated value of ore based on 'pods', with the amount of material in each pod determined by the type of system. Bulk ore sorting is typically done on-conveyor, where a pod represents several linear meters of primary crushed ore weighing between 50 kilograms and five tonnes. The classification of 'bulk ore sorting' includes truck grade measurement and assignment where decisions are made for larger pods between 10 and 200 tonnes. Even geological grade control systems can be considered a kind of bulk ore sorting, where the pods correspond to the selective mining unit (SMU), typically over 2,000 tonnes.

Leading mining and mineral processing organisations are committing considerable effort to the effective integration of bulk ore sorting with digital infrastructure to deliver a degree of precision and control not previously achieved in the mining industry

Bulk ore sorting solutions

Bulk ore sorting systems create a step-change in mining performance for large mining operations and are now a commercial reality thanks to modern technology. While particle sorting has had a long and successful history, it has typically been applied at lower capacity operations such as diamond and tin mining (Tomra Systems ASA, n.d.). The emergence of cutting-edge grade measurement devices and associated sorting infrastructure now make it possible to deliver analogous improvements at the scale of typical large mining operations that are processing tens of millions of tonnes of ore per annum.

Leading mining and mineral processing organisations are committing considerable effort to the effective integration of bulk ore sorting with digital infrastructure to deliver a degree of precision and control not previously achieved in the mining industry. By applying bulk ore sorting effectively, miners stand to materially and directly improve the economics of a mining operation or development project.

The objective of ore sorting is to upgrade process feed by identifying and rejecting waste material early in the mining or processing systems. This results in pre-concentration of high value mineralisation into a lower gross volume of material. Processing systems downstream that would have otherwise used capacity, electricity and water to process waste will now direct their efforts only to the valuable material.

What's more, the application of bulk ore sorting systems grant the operator a real-time understanding of the material that is being mined and processed.

Traditional grade control systems have relied on visual assessment or assays which are extrapolated to characterise large blocks of mined material. Reliable, tonne-by-tonne, real-time grade measurements represent a detailed data point previously unavailable in mining operations and gives miners a corresponding degree of precision in operational control.

The implementation of a technology with such a significant impact necessitates a calculated and well-thought out approach. Even a perfect technology cannot deliver full value to its owner if the implementation of that technology is flawed. NextOre provides the mining industry with cutting-edge technology, firmly supported through decades of research and first-hand experience integrating that technology effectively into a mining operation.

NextOre's flagship product is its on-belt magnetic resonance (MR) analyser used in high-throughput bulk ore sorting systems. The on-belt MR analyser allows for the grade of high throughput ore to be measured at industry-leading accuracies and speeds. It integrates measurements into a system that performs analysis, decision-making and physical diversion of ore with minimal impact on other on-site systems. Other MR-based solutions for both in-pit and in-plant applications are also being developed by NextOre and its industry partners.


0.05%
1.18%
0.31%
0.82%
0.95%

Ore upgrade and waste rejection

Modern hard rock mining is not a highly selective process. Being a complex and performance-oriented operating environment, the precision with which mining operations are carried out must be balanced against the associated practical challenges to do so. As a result, while ore is made up of a naturally formed combination of desirable high-grade mineralisation with zero-value waste, there is a natural point where it is too costly and time consuming to try to separate one from the other in the mining operation itself. As a result, current mining practices tend to favour larger economies of scale over high selectivity. Nevertheless, in-situ grade variability does exist in deposits in the form of intrusions, bedding, veins and stockwork mineralisation.

Bulk ore sorting takes advantage of this inherent grade variability (called ‘heterogeneity’) by identifying and selectively removing waste from the ore. As ore is dug from the ground, the localised variability of mineral concentrations is passed from shovel to truck and through to processing. Over longer durations, the average of this ore grade may be fairly consistent, but if it is evaluated in smaller volumes, or pods, significant variability in grade and the presence of waste can be observed.

As a result, in most cases, the smaller the pod size the better the sorting performance. Where ore has strong heterogeneity in-situ, naturally occurring sections of high- and low-grade material will present as the ore proceeds downstream. By measuring a smaller pod, those high- and low-grade pods can be clearly identified rather than being averaged across larger pods. Once identified, the pods of waste are removed, reducing the overall tonnage and increasing the grade. As pod sizes increase and grade is averaged over more material, the probability of desirable mineralisation being present increases. The result is that either less waste material can be rejected, or a higher proportion of contained metal is lost.

However, as pod sizes decrease, capital intensity and operational complexity tends to increase. Particle sorting systems show how this occurs. These systems are capable of carrying out material separation and are effective at providing good recovery and rejection rates. They have produced excellent results at tin, tungsten and diamond mines (Tomra Systems ASA, n.d.). However, a typical high-throughput particle sorter will have nameplate capacity of 150 to 250 tonnes per hour, and as high as 300tph (Tomra Sorting Solutions, 2015), whereas typical mining rates for base metals and bulk commodities are in the order of thousands of tonnes per hour. Additionally, particle sorters are constrained to a narrow band of feed sizes and require the installation of material preparation equipment such as crushing and screening, and may need multiple sorting units to manage a typical mining throughput.

NextOre's on-conveyor bulk ore sorting systems balance high sorting performance with practicality and low cost. NextOre MR Analysers are typically fed with primary crushed material and the analyser can be retrofitted in a 12-hour shutdown to standard mine-site conveyor belts. Throughput capacity is between 100 and 5,000 tonnes per hour with zero loss in measurement sensitivity at higher throughputs. The MR analyser can measure grades quickly and accurately, with demonstrated capability to provide real-time measurements at one to five second intervals. This corresponds to pods of 30 to 150 kilograms for small operations (1Mtpa) and 1.0 to 5.0 tonnes for larger operations (10-40Mtpa). Diversion of ore is then performed by a chute flop-gate or dead-box diverter downstream from the analyser.

The sorting performance achievable at each site is dictated by the in-situ heterogeneity and heavily influenced by how well it is preserved despite mixing from truck and shovel operations and other process handling. NextOre is targeting operations with highly suitable geological and operational conditions to deliver between a 15 percent and 40 percent reduction in tonnes equivalent or improved metal recoveries.

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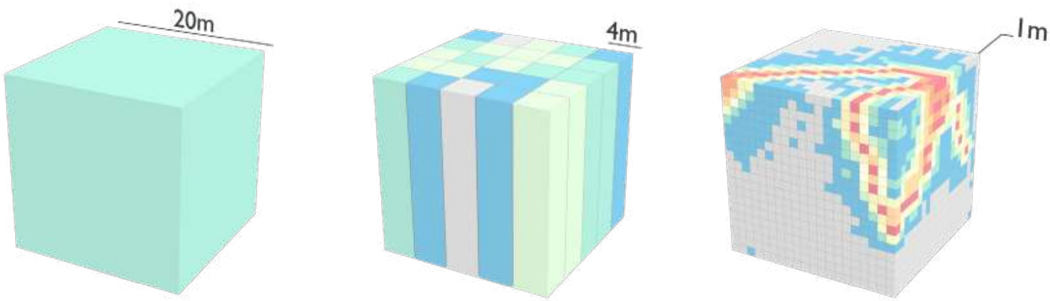
The smaller the pod size the better the sorting performance

	Grade
	≤0.05%
	>0.5%
	>0.10%
	>0.15%
	>0.20%
	>0.25%
	>0.30%
	>0.35
	>0.40%
	>0.45%



		A. Block Model			B. Grade Control Drilling			C. Bulk Ore Sorting		
		Pod size: 23,200 tonnes			**Pod size:** 900 tonnes			**Pod size:** 2.9 tonnes		
		In-situ	**Ore**	**Waste**	**In-situ**	**Ore**	**Waste**	**In-situ**	**Ore**	**Waste**
Cut-off	*%Cu*		0.15%			0.15%			0.15%	
Weight	*tonnes*	23,200	0	23,000	23,200	9,280	13,920	23,200	6,470	16,730
Grade	*%Cu*	0.13%	0	0.13%	0.13%	0.17%	0.10%	0.13%	0.30%	0.06%
Cu contained	*tonnes*	29.6	0	29.6	29.6	15.4	14.2	29.6	19.5	10.1

Figure 1 - The same block is interrogated with increasing levels of detail from smaller pod sizes

Technology advantage

NextOre's mining and mineral processing solutions apply cutting-edge MR technology to deliver measurements with industry-leading accuracy, speed and confidence. Previously used in healthcare, this is a highly sophisticated and new application of MR technology.

MR technology was developed by CSIRO, NextOre's shareholder and research and development partner. The technology was first applied to the detection of minerals at the CSIRO facility in New South Wales, Australia in the early 2000's. The first full-scale on-belt MR analyser was installed at an underground copper-gold mining operation in Australia in 2013. Since then, CSIRO and NextOre have shipped analysers around the world for use in bulk ore sorting.

MR works by quickly pulsing radio waves into a moving sample of ore and measuring the response. The radio signal is tuned specifically to the signature resonant frequency unique to the target mineral. The response signal received is directly proportionate to the number of metal atoms within the sensor volume in the tuned mineral phase (i.e. copper as chalcopyrite). This number of metal atoms is calculated as a weight and paired with a weightometer reading to produce real-time grade measurements.

Whole of ore

NextOre's on-belt MR analyser measures 100 percent of the material on the conveyor belt for metal content, regardless of its size, shape, moisture content or rock type. The technology is highly penetrative, and the sensor is designed to have an even measurement field within the full sensor volume.

Precise metal measurement

MR analysers are factory tuned for direct detection of the dominant economic minerals in ore. Rather than detecting a geophysical or chemical characteristic of the ore at the surface and using that information to infer grade, the MR analyser directly measures the number of metal atoms. The MR analyser detects tuned minerals only and delivers a signal that is very 'clean', meaning that the presence of other minerals, rock or metals, will not interfere with the performance of the sensor. As such, MR analysers do not produce grade estimates, they produce grade measurements. Miners can be confident using these measurements for operational decision making.

The radio signal is tuned specifically to the signature resonant frequency unique to the target mineral

Fast and accurate

MR can deliver small pod size sorting by producing real-time measurements quickly. NextOre's MR analysers have demonstrated the capability to produce a three-sigma detection limit of 0.07%Cu and standard deviation of +/-0.023%Cu over two second measurement intervals for chalcopyrite and more quickly for iron ore minerals. By reducing the measurement interval, a short conveyor belt can be used after the analyser and before the diverter gate, allowing the ore sorting system to more easily be integrated into existing conveying systems.

Simple

MR analysers are factory calibrated for target minerals. Ongoing calibration is not necessary after confirming calibration on-site during commissioning. Data output can be customised to integrate with any local or network SCADA systems.

Safe

MR technology is simple to install and uses non-ionising radiation so is safe for operation near workers. Radio signal strength next to a working analyser is orders of magnitude below any working exposure limits. Minimal shielding is required to achieve this, with the sensor and shielding weighing around 400 kilograms depending on belt size.

CSIRO

MAGNETIC RESONANCE TECHNOLOGY DEVELOPED BY CSIRO

CSIRO is Australia's national science research agency, with a purpose to solve the greatest challenges using innovative science and technology. CSIRO's proud legacy includes the invention of fast Wi-Fi, Aerogard and polymer banknotes. From agriculture, to energy-efficiency, to aero-space engineering and hundreds of sectors in-between, CSIRO prides itself in the development of ground-breaking technologies which have sound and proven scientific foundations.

"Everything we do is focused on creating measurable economic, environmental and social benefits that better our world and Australia's place in it."

- CSIRO

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Improved recovery

Bulk ore sorting can deliver an overall **increase** in metal recovery to mining operations. While this can be counter-intuitive, improved recovery is achieved by recovering mineralisation from low grade or marginal ore and improving its grade without displacing high value mill feed. Effectively, mining recovery is increased by capturing a portion of metal that would otherwise end up in waste dumps. The result is an increase in metal directed to the processing plant without a commensurate increase, and often a decrease, in gross ore tonnage. The Metso case study shown on the next page shows how the improvement to mining recovery is achieved in detail (Metso, 2015).

Without changing the mining cut-off grade and managing the associated change in ore/waste movements, an increase in metal recovery is still achievable. Increased metal recovery can also be achieved by correcting truck mis-assignments. Mis-assignment of trucks, either waste sent to processing as ore or vice-versa, is a little known but ubiquitous problem, and it is more prevalent in operations where average ore grade is relatively close to the cut-off grade. For operational practicality, many mine sites assign ore grade based on a Selective Mining Unit (SMU) which is "...sized no smaller than the equivalent of two truckloads" (Rocca & Sebbag, 2007). The actual grade of material in a truck may vary significantly, but it is assigned one average grade over the SMU block.

While conventional grade control systems and skilled geologists can achieve reasonable grade accuracies over large volumes, the error in grade on a truck-by-truck basis is significant. NextOre has observed actual ore grades, as measured by MR analyser, to differ from truck-by-truck grade estimates by over 20 percent (relative) in 75 percent of trucks.

Bulk ore sorting provides a high-throughput, accurate system to measure grade and automatically direct that material appropriately. The mis-assignment of trucks is eliminated, and marginal/low grade ore can be precisely managed according to the most valuable outcome possible. This is all achieved in a system that introduces minimal complexity to the mining system. Fleet management decisions do not need to be integrated with the sorting system. Trucks carrying marginal, uncertain, or low-grade material can be sent to the sorting plant along with high grade. The sorting plant will make a determination for each pod, based on a cut-off grade programmed by the mine operator, and direct it to the appropriate destination.

Bulk ore sorting is able to produce an increase in metal recovered from mining without a commensurate increase, and often a decrease, in gross ore tonnage

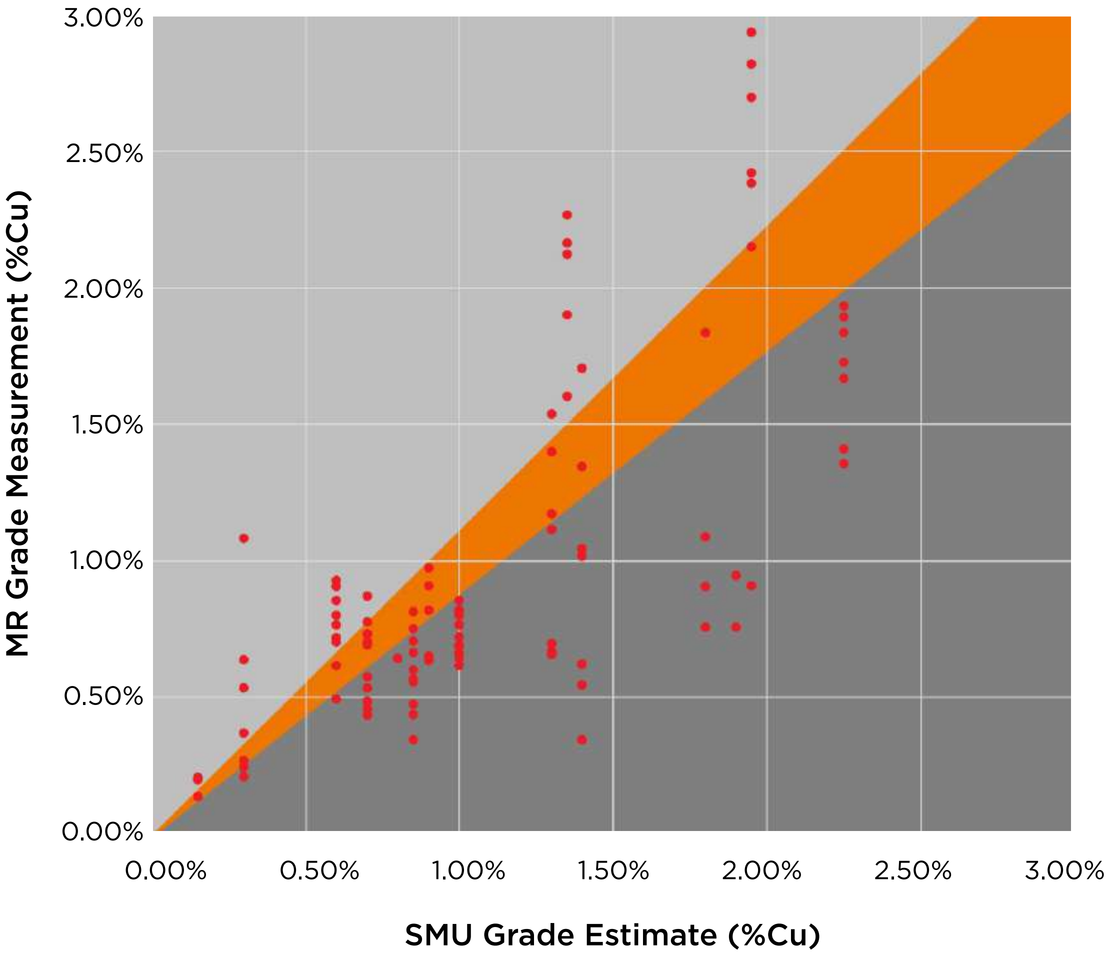


Figure 2 - Accuracy of SMU grade estimates versus MR grade measurements observed in full scale mining operations by NextOre.

Case Study: Metso

A paper from the Metso Process Technology & Innovation team published in 2015 evaluates the application of bulk ore sorting to demonstrate its impact on a theoretical mine. Bulk ore sorting represents a material change to the mining system, and as such necessitates a holistic analysis of changes to physical flows and associated costs. The results below are summarised from the Metso paper.

The case study examines a large copper deposit mined as an open pit under two operational scenarios – the first without bulk ore sorting and the second with ore sorting applied. When ore sorting is applied, run of mine ore is fed directly to a bulk ore sorting plant. The rejected waste material is rehandled and disposed of along with waste from the mine, while upgraded material is fed to the processing plant.

The authors of the case study assume 30 percent waste rejection and 90 percent recovery from the bulk ore sorting plant. Relative to results observed by NextOre in customer installations of sorting plants and MR analysers, these are conservative figures. However, every orebody will exhibit different bulk ore sorting performance based on its in-situ grade variability and must be evaluated on a case-by-case basis.

Outcomes:

13% increase in annual copper production
Increase in head grade from 0.39% to 0.45%
7% reduction in total tailings produced
4.4% increase in overall metal recovery
23% reduction in copper sent to waste dumps or left behind in pits

	Unit	Without Bulk Ore Sorting	With Bulk Ore Sorting
Waste Mined	Mt	60*	40*
Ore Mined	Mt	110	146
Mining Cut-Off Grade	%Cu	0.25%	0.20%
Grade	%Cu	0.39%	0.35%
Strip Ratio	W:O	0.55*	0.28*
Sorting			
Feed	Mt	0	146
Sorting Rejection	%wt	0%	30%
Sorting Recovery	%	100%	90%
Processing			
Process Feed	Mt	110	102
Head Grade	%Cu	0.39%	0.45%
Cu in Feed	Kt	433	452
Plant Recovery	%	90%	90%
Cu in Concentrate	Jt	390	407

Average Annual**	Unit	Without Bulk Ore Sorting	With Bulk Ore Sorting
Processing Capacity	Mtpa	10	10
Mine Life	Years	11.0	10.2
Head Grade	%Cu	0.39%	0.45%
Copper Contained	Ktpa	39	45
Recovery	%	90%	90%
Cu in Concentrate	Ktpa	35	41

*Calculation by NextOre - Strip ratio assumption based on pit shell diagram in Metso report

**Calculation by NextOre - Assumes a fixed processing plant size of 10Mtpa

Without Bulk Ore Sorting

Cut-off grade 0.25%
Average head grade 0.39%

Total ore to plant 110 million tonnes
Total Cu to plant 433 thousand tonnes

0.00	0.00	0.10	0.15	0.20	0.30	0.30	0.50	0.20	0.10
0.00	0.10	0.15	0.20	0.25	0.40	0.70	0.40	0.25	0.10
0.10	0.10	0.15	0.25	0.40	0.60	0.70	0.30	0.15	0.10
0.10	0.10	0.20	0.30	0.50	0.60	0.40	0.20	0.10	0.00
0.00	0.15	0.25	0.30	0.40	0.30	0.20	0.10	0.00	0.00
0.00	0.10	0.15	0.25	0.20	0.15	0.10	0.00	0.00	0.00
0.00	0.00	0.10	0.15	0.15	0.00	0.00	0.00	0.00	0.00

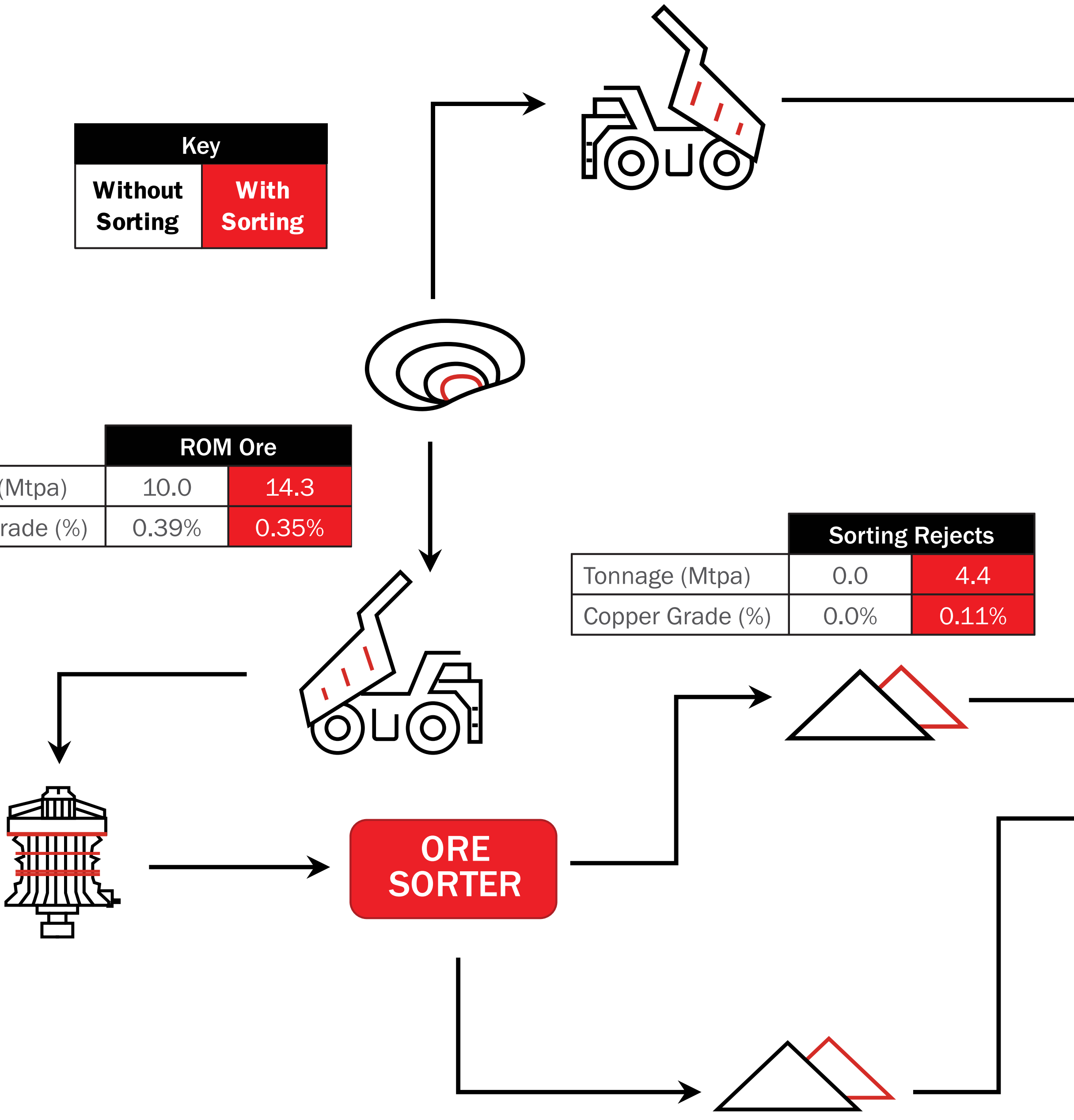
With Bulk Ore Sorting

Cut-off grade 0.20%
Average head grade to sorter 0.39%
Average head grade to plant 0.45%

Total ore to plant 102 million tonnes
Total Cu to plant 452 thousand tonnes

0.00	0.00	0.10	0.15	0.20	0.30	0.30	0.50	0.20	0.10
0.00	0.10	0.15	0.20	0.25	0.40	0.70	0.40	0.25	0.10
0.10	0.10	0.15	0.25	0.40	0.60	0.70	0.30	0.15	0.10
0.10	0.10	0.20	0.30	0.50	0.60	0.40	0.20	0.10	0.00
0.00	0.15	0.25	0.30	0.40	0.30	0.20	0.10	0.00	0.00
0.00	0.10	0.15	0.25	0.20	0.15	0.10	0.00	0.00	0.00
0.00	0.00	0.10	0.15	0.15	0.00	0.00	0.00	0.00	0.00

Diagram of conceptual mining operation according to NextOre calculated annual physicals



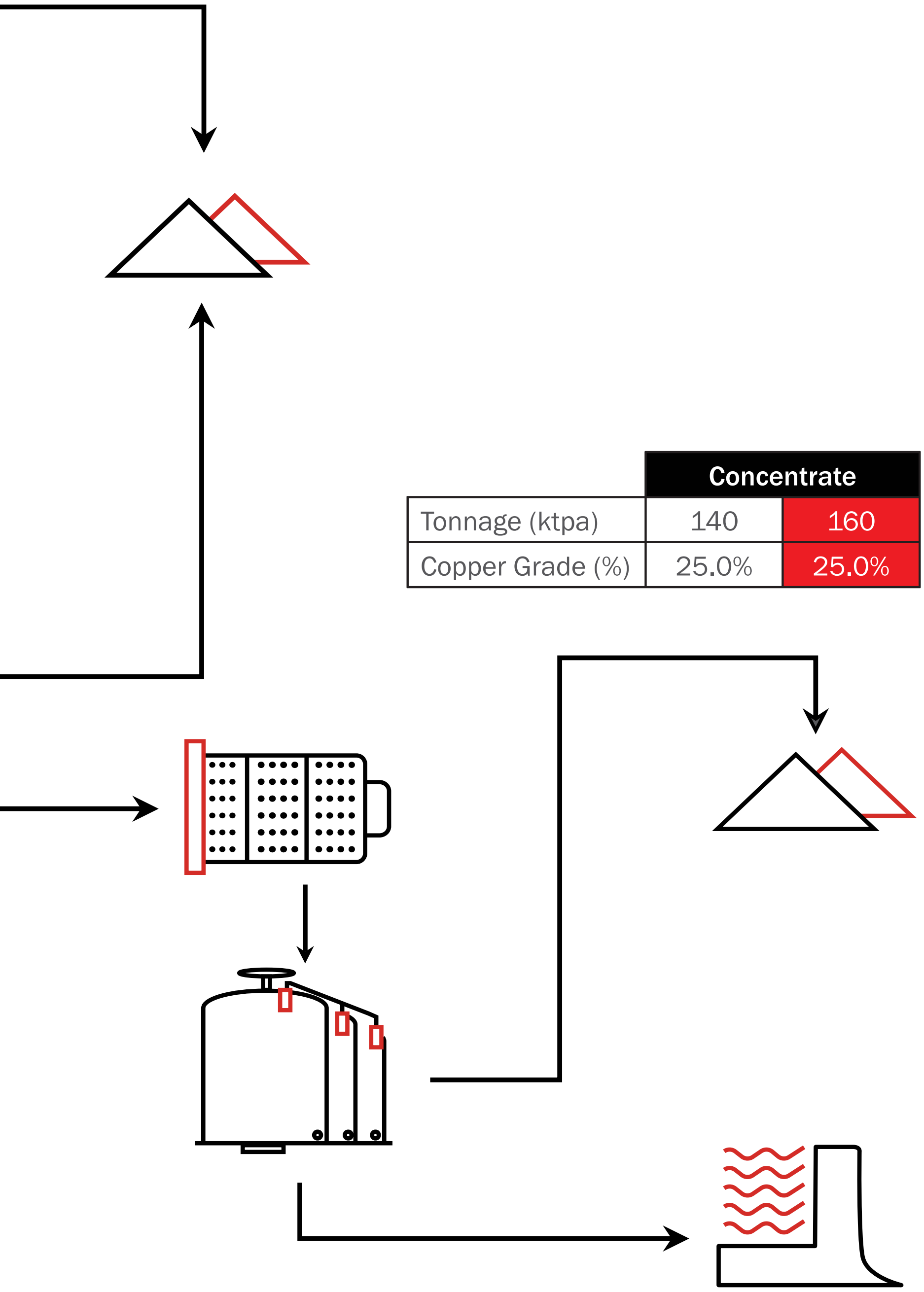
Key	
Without Sorting	With Sorting

	ROM Ore	
Tonnage (Mtpa)	10.0	14.3
Copper Grade (%)	0.39%	0.35%

	Sorting Rejects	
Tonnage (Mtpa)	0.0	4.4
Copper Grade (%)	0.0%	0.11%

	Mill Feed	
Tonnage (Mtpa)	10.0	10.0
Copper Grade (%)	0.39%	0.45%

	Waste Dumps	
Tonnage (Mtpa)	6.0	4.0
Copper Grade (%)	0.13%	0.08%



	Concentrate	
Tonnage (ktpa)	140	160
Copper Grade (%)	25.0%	25.0%

	Tailings	
Tonnage (Mtpa)	9.98	9.98
Copper Grade (%)	0.04%	0.05%

Precise control

Leading mining and mineral processing groups believe that mining, along with other industries, is undergoing a fresh revolution in productivity. After a prolonged period of declining productivity, the potential is now being acknowledged to achieve breakthroughs in performance through digital and technological innovations that could transform key aspects of mining (Geraghty, Pujol, Sellschop, & Durrant-Whyte, 2015). While it is difficult to attribute this revolution to individual technologies, much of the advancement can be broadly categorised as digitalisation or the application of data science; the intelligent collection, synthesis and use of data.

Data scientists are now tasked with the systematic overhaul of age-old and disparate sets of systems used across the mining sector, with the goal to improve efficiency and performance. This improvement in performance is expected to be the result of a deeper and more holistic understanding of operations through examination of abundant data. Once understood, system controls can be implemented that take place in real-time, rather than retrospectively. Certainly, the potential benefit is significant, but it is no small task. The sheer volume of data produced daily from any mining operation is staggering.

For an improvement in performance to be achieved through data science, it is a necessary condition that the original data used is accurate and of high quality (Cai & Xhu, 2015). Where the goal is a deeper and more holistic understanding of an operation through the examination of data, inaccurate original data that is biased or outright incorrect can result in counterproductive actions. The risk represented is that a lot of effort is exerted on behalf of the industry and costs are incurred without being able to deliver a genuine result. Put simply, if you feed garbage data in, you can expect to get garbage results out.

The grade of run-of-mine ore is a fundamental piece of production data for which conventional mining has no accurate real-time source. Ore grade is estimated according to block models and re-estimated by pit or underground geologists as more precise information becomes available. An accounting system is often in place to track material in stockpiles that refers back to previous grade estimates. On a scheduled reporting cycle, reported grades and contained metal are then reconciled back from concentrate or metal production to the ore extracted from the mine. Evidence for a lack of reliable original data takes the form of the all-too-familiar disagreements between mining and processing departments on site because no ultimate measurement is available that is accurate and unbiased.

Reliable, accurate and real-time grade measurements delivered on a tonne-by-tonne basis represent a powerful and disruptive tool in the hands of site personnel. It decouples the decision-making process from daily and weekly reporting cycles.

Where unforeseen changes would otherwise be recognised in weekly or monthly reporting, well after the point in time when corrective action could be taken, results are delivered in real-time and decisions can be made accordingly. Equally important is the ability to monitor the impact of this real-time decision making.

A practical example of this impact is in a conventional, modern mine where a decision to adjust the mining cut-off grade on a given day by +0.05%Cu would be non-sensical to an experienced miner. The operational effort necessary to enact that change would be significant and disruptive. Whereas the impact, particularly if it were highly negative, would be impossible to recognise and reverse in a timely matter. The results of the off-the-cuff change would need to be reviewed once the reporting cycle completed and the specific impact of that change somehow untangled from the multitude of other factors impacting production during that reporting period.

Alternatively, where an MR analyser is installed, each pod of material will have a grade measurement assigned. Not only would the impact of a +0.05%Cu change to the cut-off grade be observable, it could be reliably compared in real-time to the result where there was no change made.

Further benefits of this data include:

- Designer mill feed, with a known grade of ore fed to the processing facility and having a pre-set grade variability
- Real-time block model validation, with material grade immediately reconciled to orebody estimates
- Tracking of ore and the ability to identify where in the value chain losses are occurring
- Potential for reduced mill throughput variability and improved circuit stability with the reduction of hard or deleterious waste ore
- Optimise design for greenfields circuit to minimise capex and improve the net present value of the project.
- Optimise existing circuit to de-bottleneck the grinding mills which are frequently the highest constraint.

Reliable, accurate and real-time grade measurements delivered on a tonne-by-tonne basis represent a powerful and disruptive tool in the hands of site personnel

Reduced footprint

Mines and mineral processing plants generally are much more efficient at producing waste than they are at producing the marketable commodity itself. Globally, the grade of metal deposits is decreasing, and the strip ratio of ore is increasing. It is estimated that annual mine waste and tailings production ranges from 4.5 to 6.3 billion tonnes per year (Mudd & Boger, 2013). In copper, the proportion of tailings to concentrate product can be as high as 90 to 98 percent and is increasing as grades decline.

Lower grades also correspond to higher consumption of electricity and water from mining operations. An average gold mine uses between 25 and 150kWh of electricity per tonne of ore processed (Calvo, Mudd, Valero, & Valero, 2016). Similarly, a conventional copper processing plant uses between 0.7 and 1.0m3 of water per tonne of ore (Suvio, Kotiranta, Kauppi, & Jansson, 2017). Holistic tailings management strategies and new technologies to improve efficiency and water recycling are enabling a reduction in these statistics, but if more tonnes of feed are required per unit of metal production, overall consumption will still increase.

As global grades decline, trends in tailings production and resource consumption will continue and processing plants will be required to expand capacity to achieve the same level of production. This trend poses increasing economic, environmental and social problems for mining companies. Several high-profile tailings dam failures in recent years have resulted, fairly, in increased social awareness of the risks posed by tailings storage facilities. Developers and existing operations will now be expected to make material improvements over industry standards.

Decreasing mill feed tonnes by bulk ore sorting ahead of mineral processing leads to a roughly proportionate decreases in tailings production and in water and reagent consumption.
36 percent of utilised energy on a mine site has been attributed to comminution (Ballantyne, Powell, & Tiang, 2012), translating to proportion reductions in energy consumption relative to approximately one third of the site's energy consumption.

Materials handling

While the installation of NextOre's sensors is low impact, with sensor retrofitted to existing conveyors in a 12-hour shut-down, consideration must be given to the impact on materials handling systems when implementing bulk ore sorting systems. Focal points of consideration where to locate the bulk ore sorting system and how to configure the waste disposal system for material produced as a bi-product of sortation.

Bulk ore sorting systems achieve the highest efficiency when applied to ore that has undergone the minimum possible mixing. In the mining operation, each step of dumping and loading ore further homogenises the material and decreases the presence of pods of barren waste. The best sorting performance is achieved when ore is trucked from the mining face directly to the sorting plant without being rehandled on the ROM or through intermediate stockpiles.

Similarly, in determining the best location for installation of the bulk ore sorting system, the most common installation point for on-conveyor bulk ore sorting systems is the primary crusher product conveyor. This allows the ore to avoid mixing from intermediate materials handling equipment. Screens, transfer chutes, bins and crushers all contribute further homogenisation to the ore and negatively impact grade improvement and waste rejection rates.

In certain operations, bulk ore sorting systems may benefit from the application of grade engineering concepts. For example, ore from copper deposits can exhibit the well-documented tendency for disproportionately high quantities of copper metal to deport in fine size fractions (Carrasco, Keeney, & Walters, 2014). Furthermore, particle mobility and degree of homogenisation has been observed to increase with fine size fractions. As a result, the performance of certain bulk ore sorting plants can be improved by scalping fines ahead of bulk ore sorting. NextOre assists companies and their engineering teams with technical analysis during the design stage to develop the optimal sorting plant configuration to generate the best outcome in terms of cost and performance.

A further consideration that is required during design is the handling of waste bi-product produced from the sorting plant. At large operations this can equate to millions of tonnes of additional movements. The crushed waste product can be transported either by truck or fixed conveyor. Given the material is frequently crushed, it can also be useful for co-deposition with tailings for dry stack solutions.

Decreasing mill feed tonnes by bulk ore sorting ahead of mineral processing leads to a roughly proportionate decreases in tailings production and in water and reagent consumption

Conclusion

After many years of development and study, bulk ore sorting is now a commercial reality for the mining and mineral processing industries. Enabled by the advancement of new, high accuracy sensing technologies, the improvements in performance previously reserved for low-throughput operations can now be applied more broadly to globally significant metals mines.

This emergence of technologies coincides with increasing economic and social pressure to improve mining and processing efficiencies. Many large mines are maturing, with the high margin/high grade cores of the deposits largely consumed and main feed increasingly dominated by lower grade material. To maintain previously achieved levels of metal production, a step-change in efficiency is necessary.

NextOre's MR technology, developed by CSIRO, is an enabling technology that allows for speed and accuracy of bulk ore sorting operations to deliver previously unachievable capabilities. MR analysers have been deployed at global mining operations and have proven capability in the field across a wide range of throughput rates both in passive sensing and in active bulk ore sorting systems. NextOre is on the forefront of bulk ore sorting and can offer sorting systems customised to existing assets or development projects.

References

- Ballantyne, G. R., Powell, M. S., & Tiang, M. (2012). Proportion of Energy Attributable to. 11th Mill Operators' Conference, (pp. 25-30). Hobart.
- Cai, L., & Xhu, Y. (2015). The Challenges of Data Quality and Data Quality Assessment in the Big Data Era. Data Science Journal, 14, 2.
- Calvo, G., Mudd, G., Valero, A., & Valero, A. (2016). Decreasing Ore Grades in Global Metallic Mining: A Theoretical Issue or a Global Reality? Resources.
- Carrasco, C., Keeney, L., & Walters, s. (2014). Development of geometallurgical laboratory tests to characterise metal preconcentration by size. Proceedings XXVII International Mineral Processing Congress, (pp. 1-21). Santiago.
- Duffy, K.-A., Valery, D. W., Jankovic, D. A., Holtham, P., & Valle, R. (2015). In Search of the Holy Grail - Bulk Ore Sorting. Austmine.
- Geraghty, R., Pujol, F., Sellschop, R., & Durrant-Whyte, H. (2015, November). How digital innovation can improve mining productivity. Retrieved from McKinsey & Company, Metals & Mining, Our Insights: https://www.mckinsey.com/industries/metals-and-mining/our-insights/how-digital-innovation-can-improve-mining-productivity
- Leuangthong, O., Neufeld, C., & Deutsch, C. V. (2003). Optimal selection of selective mining unti (SMU) size. International Conference on Mining Innovation (MININ), (pp. 1-16). Santiago, Chile.
- Mudd, G., & Boger, D. (2013). The ever growing case for paste and thickened tailings - Towards more sustainable mine waste management. AusIMM Bulletin, 56-59.
- Rocca, F., & Sebbag, M. a. (2007). Buzwagi open pit study. Proceedings SIxth Large Open Pit MIning Conference 2007 (pp. 119-128). Perth, WA: AusIMM.
- Suvio, D. P., Kotiranta, T., Kauppi, J., & Jansson, K. (2017). Towards minimum impact copper concentrator - The link between water and tailings. 13th International Mine Water Association (IMWA) Congress, 226-236.
- Tomra Sorting Solutions. (2015). COM Tertiary with XRT-technology (English).
- Tomra Systems ASA. (n.d.). Case studies mining sorting solutions. Retrieved from tomra.com: https://www.tomra.com/en/sorting/mining/case-studies