Process Technology & Innovation

In Search of the Holy Grail – Bulk Ore Sorting

Austmine 2015 Whitepaper

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16 February 2015
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Introduction

As high grade ore deposits are depleted, remaining deposits are generally lower grade and more difficult to extract, requiring the movement and processing of larger volumes of material per tonne of valuable mineral. The transportation, comminution and processing of these large volumes is expensive and energy intensive. Low grade orebodies generally contain a large proportion of liberated barren gangue which may be removed at coarse sizes. This rejection of gangue from the feed material, termed pre-concentration, reduces the total mass and increases the grade of ore proceeding to the next stage of processing (Pokrajcic and Lewis-Gray, 2010). The rejection of material below the defined cut-off grade avoids feeding the plant with material that will cost more to process than the respective value of the contained valuable mineral.

The aim of pre-concentration is to remove barren material at as coarse a particle size and as early in the process as possible. Gangue is usually high in silicates and typically harder and more competent than the valuable minerals. Removal of this hard and barren material prior to comminution stages has the potential to significantly reduce energy consumption and processing costs, and may also reduce ore transport requirements. Pre-concentration can significantly improve resource efficiency by upgrading uneconomic or marginal material and/or increasing production rates. It may be possible to reduce the cut-off grade depending on the net balance of reduced processing costs (due to gangue rejection) and new costs associated with pre-concentration and mining additional material. More valuable metal may be extracted from the resource while the processing plant treats less tonnes at higher feed grade.

For effective pre-concentration, it is only necessary to have liberated gangue that can be removed; the valuable minerals do not need to be liberated. There are several technologies that may be applicable for pre-concentration including: gravity processes, magnetic separation, sensor based ore sorting and screening. The suitability in each case depends on the ore properties. This paper looks specifically at sensor based ore sorting; however, other alternatives which may be cheaper and/or simpler such as gravity concentration and pre-screening should always be evaluated.

Pre-concentration with an ore sorter has the added advantage that it can complement mining selectivity at the bench or stope by determining grade. It is an efficient way to deal with uncertainties of grade, particularly where the complexity of mine geology makes the estimation of grade difficult. This helps the mining operation to achieve the planned cut-off grade and optimise extraction of the resource.

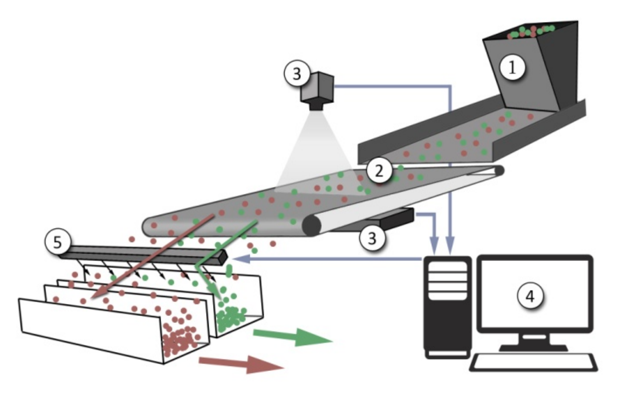
Ore sorting technology

Ore sorting relies on measuring a property that is different in the valuable and waste components using some form of sensor. A variety of sensors are available, and those commonly used in industrial applications include photometric, electromagnetic, radiometric and x-ray. A summary of sensor types is provided in Table 1.

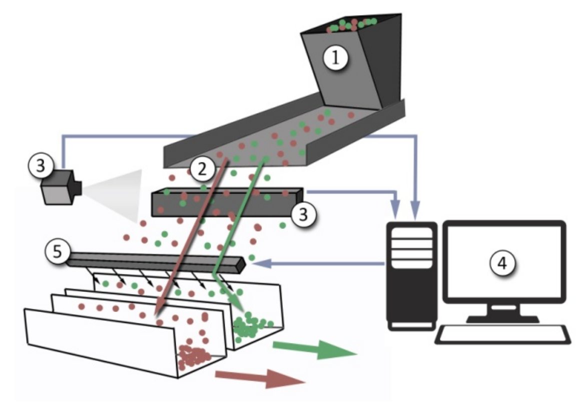
Sensor based ore sorting is not new, and has been shown to be technically feasible. However, in the minerals industry, it is currently only used in some niche applications such as industrial minerals (e.g. calcite, rock salt or talc), diamonds and other gemstones. The current technology, based on the measurement and separation of individual particles, is well documented in the literature (for example Wotruba, 2006; Bergmann, 2009; and Manouchehri, 2004) and in publications by suppliers.

Current sorters can be classified as either belt or chute type sorters, and both require five process steps: material conditioning, material presentation, detection, data processing and separation, as shown in Figure 1. Careful feed preparation is required so that individual particles can be detected and measured, and ejection of single particles is usually achieved by blasts of compressed air. Consequently, current sorters have very low capacity (up to 300 tph for larger particles and much less for smaller particles). They would not be economically viable for high tonnage pre-concentration. For these cases, ore sorting needs to be applied to bulk quantities of ore, such as on a fully loaded conveyor belt or a loaded truck tray.

Belt Type Sorter



Chute Type Sorter



Material conditioning - Sizing to provide feed in narrow size band and washing (scrubbing) if necessary
Material presentation - Present individual particles to sensors (belt or chute/freefall)
Detection – Measurement of material properties with a sensor or a combination of appropriate sensors
Data processing – Analysis of data from sensors to assign individual particles as accept or reject
Separation - Mechanical separation of accepts and rejects (usually by air ejection).

Figure 1: Current ore sorting technology (for individual particles)

The concept of bulk ore sorting involves the separation of a large volume of barren gangue from a fully loaded conveyor belt based on the grade as measured or inferred from a sensor measurement. Most mining deposits are heterogeneous which should allow the separation of such large volumes if sensing is conducted early in the process, before excessive handling and mixing occurs. Highly disseminated ores are unlikely to be amenable to bulk ore sorting.

A review of existing sensor technologies indicates that most are currently not suitable for bulk ore sorting, as they are either not sufficiently penetrating or are too slow for effective separation, as can been seen from the summary of sensors provided in Table 1. For example, laser-induced breakdown spectroscopy (LIBS), laser-induced fluorescence (LIF) and photometric sensors are surface only measures (not penetrating into the rock). X-ray fluorescence (XRF) has a beam size and penetration of only a few millimetres. Therefore, these sensors cannot provide a representative measure for large quantities of heterogeneous material such as required for bulk sorting.

Table 1: Summary of sensors

Sensor Type	Separation Property	Areas of application	Current application / development status	Speed	Penetration
Magnetic resonance (MR)	Excitation and detection of specific radio frequency spectral lines	Only applicable to selected minerals (currently chalcopyrite)	Development for bulk sorting	Seconds	Penetrating
Radiometric (RM)	Natural gamma radiation	Uranium, precious metals	Particle sorting	Real-time	Penetrating
Dual Energy X-ray Transmission (XRT)	Absorption x-rays (atomic density)	Base and precious metals, industrial minerals, fuel, diamonds	Particle sorting	Real-time	Partly penetrating
X-ray Fluorescence (XRF)	The emission of secondary (fluorescent) X-rays	Diamonds	Particle sorting	Real-time	Surface
Colour (CCD Colour Camera)	Reflection, absorption, transmission	Base and precious metals, industrial minerals, diamonds	Particle sorting	Real-time	Surface
Photometric (PM)	Monochromatic Reflection / Absorption	Industrial minerals, diamonds	Particle sorting	Real-time	Surface
Electromagnetic (EM)	Conductivity, permeability	Base metals	Particle sorting	Real-time	Penetrating
PGNAA	Prompt-gamma neutron activation analysis	Limestone, Fe, Al, Pb, Mn, Cu, Zn	Measurement only	Minutes	Penetrating
PFTNA	Pulsed fast and thermal neutron activation	Ni, Fe, Co, Mg, Si, Al, Mn, Cr, C, H, O	Measurement only	Minutes	Penetrating
Near Infrared Spectrometry (NIR)	Reflection, Absorption	Base metals, industrial minerals	Recycling applications	Real-time	Surface
Infrared (IR)	Heat conductivity, heat dissipation	Base metals, industrial minerals	Development	Real-time	Surface
Laser-induced breakdown spectroscopy (LIBS)	Atomic spectroscopy using a highly energetic laser pulse.	Raw materials	Raw material applications	Real-time	Surface
Laser-induced fluorescence (LIF)	A spectroscopic method, measurement of photon emissions	Raw materials	Raw material applications	Real-time	Surface
Eddy-current	High-frequency changing magnetic fields create strong eddy currents in the non-ferrous metal parts	Recycling	Recycling applications	Real-time	Penetrating

Prompt-gamma neutron activation analysis (PGNAA) and pulsed fast and thermal neutron activation (PFTNA) sensors measure elements and can penetrate the full cross section on a loaded conveyor belt. However, currently the measurement speeds are too slow for effective bulk ore sorting, in the order of minutes rather than seconds. It may be possible adapt these sensors for bulk sorting; the trade off would be some reduction in accuracy and increased cost.

The CSIRO is developing a sensor using magnetic resonance (MR) that has the ability to rapidly measure batches of ore on large primary production conveyors (Miljak, 2011). The MR sensor is well suited to a bulk ore sorting application as it is penetrative and can measure large throughputs on fully loaded conveyor belts. In addition, the measurement response time is rapid, thus allowing diversion of different grade streams in an ore sorting application. However, the MR sensor measures an individual mineral (not element) and may have limitations measuring ores with complex mineralogy. The sensor is currently developed for chalcopyrite, a dominant copper mineral, and with further development could potentially be applied to other minerals (Heselev, 2012).

Bulk ore sorting may incorporate more than one type of sensor to overcome the limitations of the different sensor types. It also requires a control system, to interpret the data from the sensor or sensors and make an accept or reject decision, and a diversion system such as a diverter gate to separate the valuable "batches" of ore from waste, as shown in Figure 2. Metso has developed conceptual designs for implementation on plant feed or in-pit conveyors treating up to 3,600 tph and belt speeds of up to 5 m/s. Ore sorting benefits from the natural heterogeneity of deposits, and should be implemented as early in the process as possible where the variability is greatest and to maximise the benefits. Therefore, either in-pit or plant feed conveyors provide the best opportunities for bulk ore sorting.

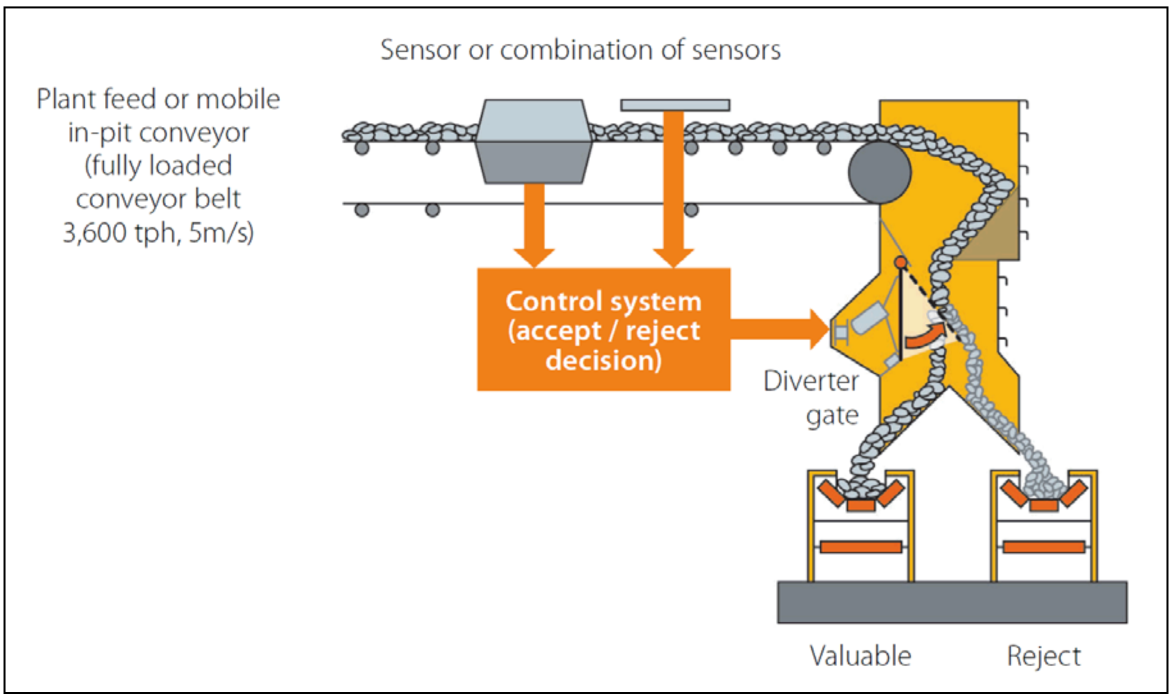


Figure 2: Metso bulk ore sorting concept

Ore variability and amenability to bulk ore sorting

Very little is currently known about the scale and frequency of grade variability on plant feed belts, as it is difficult to measure. It depends on the in-situ variability of the ore deposit and also the mining methods, ore handling, crushing and blending prior to delivery to the plant. Understanding the grade variation is important to determine the required response time for measurement and separation (diversion), and also the potential grade uplift which will determine if there is economic value in bulk sorting for each case.

Most deposits are heterogeneous; which would make them potentially amenable to upgrading with bulk ore sorting. However, current mining practices are generally designed to blend out the variation and provide a consistent, stable feed to the processing plant.

The mining industry typically takes a 'one size fits all' approach, and endeavours to treat all the ore from a deposit through one extraction process. The process is designed for the average or typical ore, and a consistent feed grade is requested from the mine so the process can be stabilised and optimised. Therefore, mining operations generally have blending strategies to deliver, as far as possible with the ore available, a stable feed grade to the plant. It is not unusual to have a number of stockpiles on the ROM pad with different grade classifications which can be fed to the process in the required proportions to achieve a desired feed grade.

Underground mines can have hundreds of draw points, and be extracting from many of these at the same time. The active draw points are generally dictated by mining requirements, but then may be selected from based on draw point grade control samples to meet plant feed grade requirements. Significant mixing occurs through ore passes, underground crushing and materials handling prior to delivery to the plant. The Northparkes block cave mines illustrate this point. The schematic layout for E26 Lift 2 mine is shown in Figure 3, and Figure 4 shows the E48 Lift 1 mine materials handling system. These demonstrate the number of draw points and materials handling steps (ore passes, bins, crushers, conveyors, feeders).

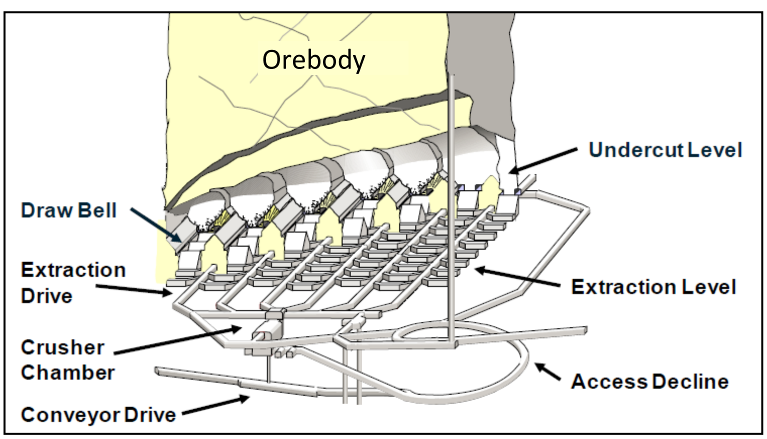
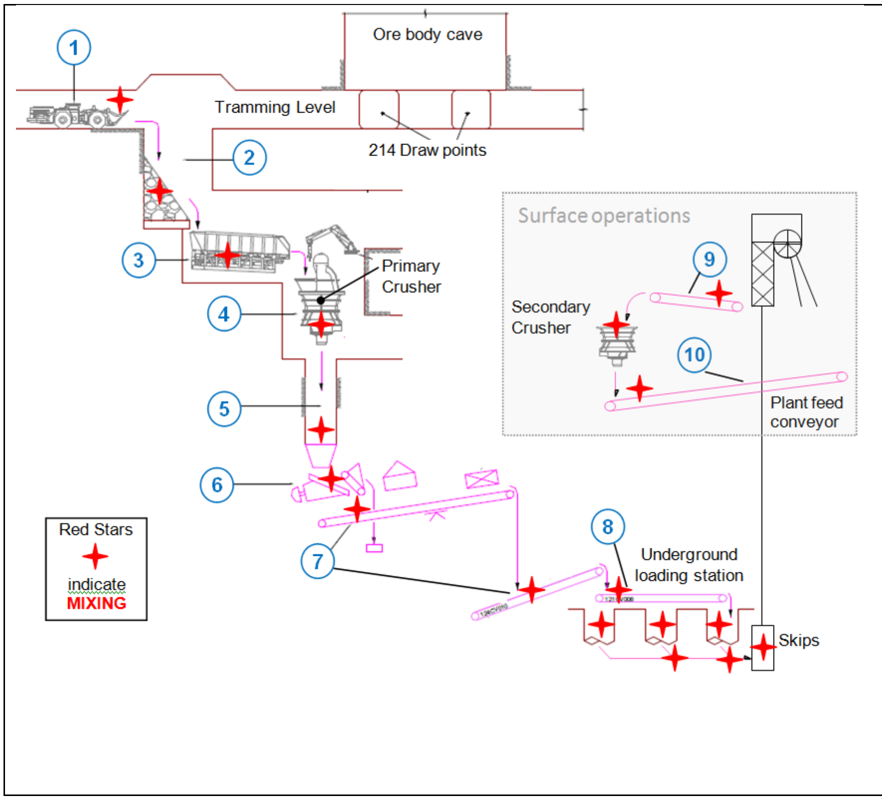


Figure 3: Schematic layout of the E26 Lift 2 block cave mine (after Butcher *et al*, 2013)



(1) Extraction from draw points by 4 – 5 continuously operating Load Haul Dump Units (12 t bucket)
(2) Ore is fed to a coarse ore bin that feeds the primary crusher (800 t live capacity)
(3) Plate feeder (1000 tph)
(4) Gyratory crusher (1000 tph)
(5) Crusher ore pass / bin (400 t live capacity)
(6) Vibratory feeder (1050 tph)
(7) Ore is transferred by high-speed inclined conveyors to the underground loading station
(8) Underground loading station - three ore passes feeding the hoisting system (two 16 t payload skips)
(9) Hoisted ore is transferred via a short conveyor to a secondary crushing station
(10) Ore from the secondary crusher to then conveyed to the concentrator by a curved high speed conveyor

Figure 4: E48 Lift 1 mine materials handling system (after Butcher *et al*, 2013)

Every time the ore is rehandled, transferred, crushed, blended etc. the degree of mixing increases; reducing the variability and thus the potential for effective separation of batches of barren gangue (waste) from ore. To maximise the value of bulk ore sorting a shift in mining practices will be required in order to exploit the natural variability in the deposit rather than blend it out.

Benefits

By removing coarse barren material, pre-concentration has the potential to significantly reduce the amount of material that requires downstream processing. If conducted as close to the mining face as possible, it can potentially reduce ore transport requirements by rejecting barren gangue and transporting less ore to the processing plant. Pre-concentration effectively upgrades the plant feed, less tonnes of ore are treated in the processing plant per tonne of product, thus reducing the costs, energy and water consumption per tonne of product.

In existing operations with fixed plant capacity the production rate can be increased after sorting due to the increase in feed grade. In Greenfields operations the size of downstream processing equipment can be reduced (reducing the capital and operating costs), or the production rate can be increased.

Pre-concentration can upgrade previously uneconomic material to increase resource utilisation, and should be factored into the cut-off grade decision. It may be possible to reduce the cut-off grade depending on the net balance of reduced processing costs (due to gangue rejection) and new costs associated with pre-concentration and mining additional material. Additional mining resources (drill and blast, load and haul, waste handling) may be required to maintain the plant feed rate due to the rejection of material (previously considered ore) by the sorter. However, this may be compensated for by the increase in plant feed grade and the subsequent reduction in downstream processing costs, increased production and greater extraction of valuable mineral from the resource.

Additionally, bulk ore sorting can reduce dilution and ore loss in mining operations by improving grade control. In some cases, mining costs may be reduced, with the bulk ore sorter providing selectivity thus allowing less selective mining processes.

The environmental footprint of the mine is also reduced due to lower energy consumption, greenhouse gas emissions and water losses per tonne of product. Less fine wet tailings are produced requiring a smaller tailings storage facility and minimising the surface impact. The waste dump area may increase; however, in some cases the dry coarse waste from the sorter could be useful as aggregate or for other fill purposes.

Bulk sorting may also be used to separate different ore types to treat separately. High grade material could be processed through a more costly but higher recovery process due to the high contained value, while the low grade material is processed through a less costly but lower recovery process. For example, some operations may benefit from treating high grade material with flotation and low grade material by heap leach. This means a mine may have a diversity of cut-off grades, depending on the cost of the processing route options ahead. It may also be possible to recover valuable components from waste dumps and low grade stockpiles (marginal reserves) that would be uneconomic to treat without upgrading.

The applications and potential benefits of bulk ore sorting are illustrated in Figure 5. Despite the apparent benefits, uptake has been slow. This is possibly due to perceptions of unacceptable metal losses, insufficient understanding of ore characteristics, and a lack of understanding of the systemic impact. Limitations in sensor capabilities, and most importantly the low throughput of the existing individual particle sorters is also a significant deterrent to application. However, metal losses in pre-concentration are offset, if not completely compensated for, by the increased recovery in downstream processes due to the higher feed grade, and the overall economics of the project benefit from reduced costs and/or increased production. A bulk ore sorting system would be much simpler, less expensive (in both capital and operating costs) and require far less footprint than the current individual particle sorting technology.

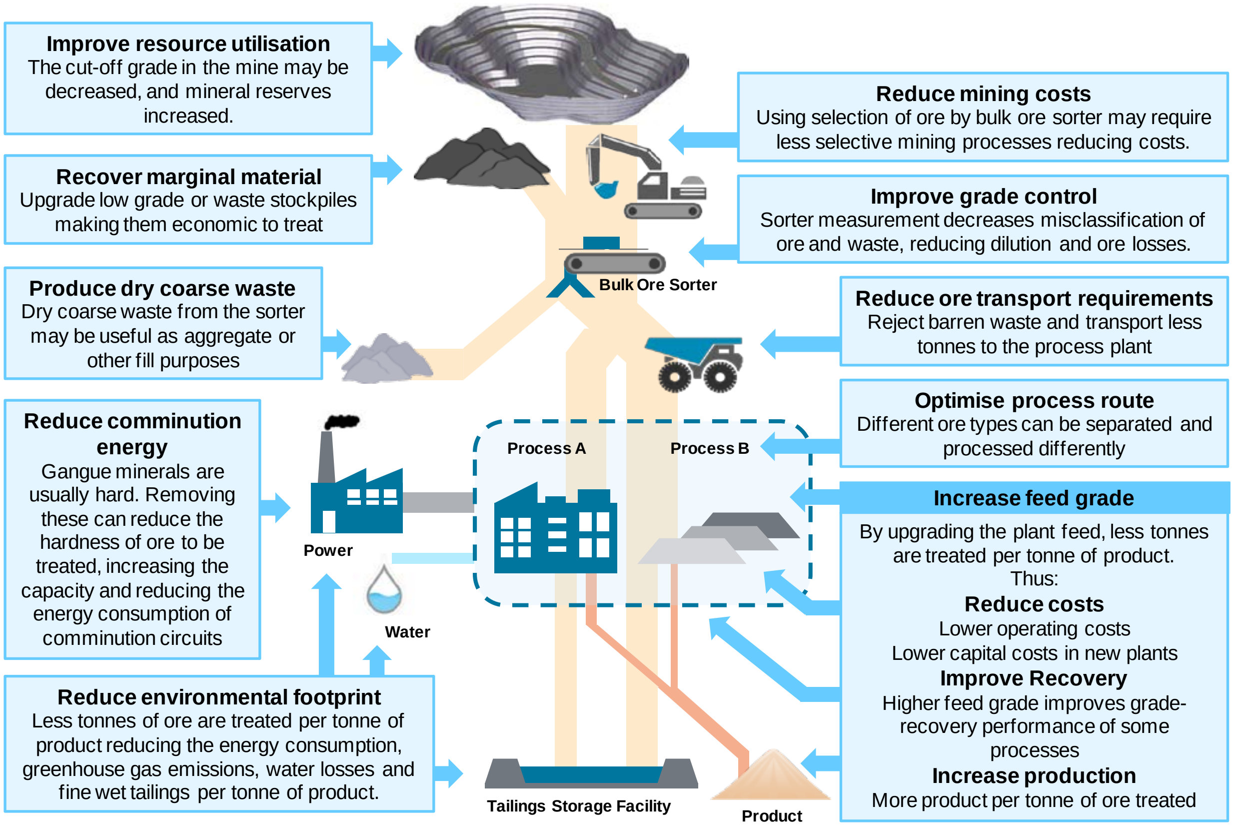


Figure 5: Applications and potential benefits of bulk ore sorting

The overall impact on project economics will of course depend on the ore deposit and characteristics, mining and processing methods, site conditions, local economic climate, etc, and needs to be evaluated on a case-by-case basis. To demonstrate the potential impact of bulk ore sorting on project economics, three different cases have been considered, these are:

- Reducing cut-off grade for a Greenfield operation
- Increasing production at an existing operation with fixed plant capacity
- Reducing ore losses and dilution through improved grade control
- Each case is discussed in the following section.

Case examples

Case 1 – Reducing cut-off grade for a Greenfield operation

Bulk sorting increases the resource utilisation by reducing the cut-off grade. More valuable metal is extracted while the processing plant treats less tonnes at higher feed grade.

A hypothetical copper deposit is considered with a grade tonnage curve as shown in Figure 6. Mining and processing cost assumptions were made based on operations at similar copper deposits and used to conduct some preliminary break-even cut-off grade calculations, as shown in Table 2.

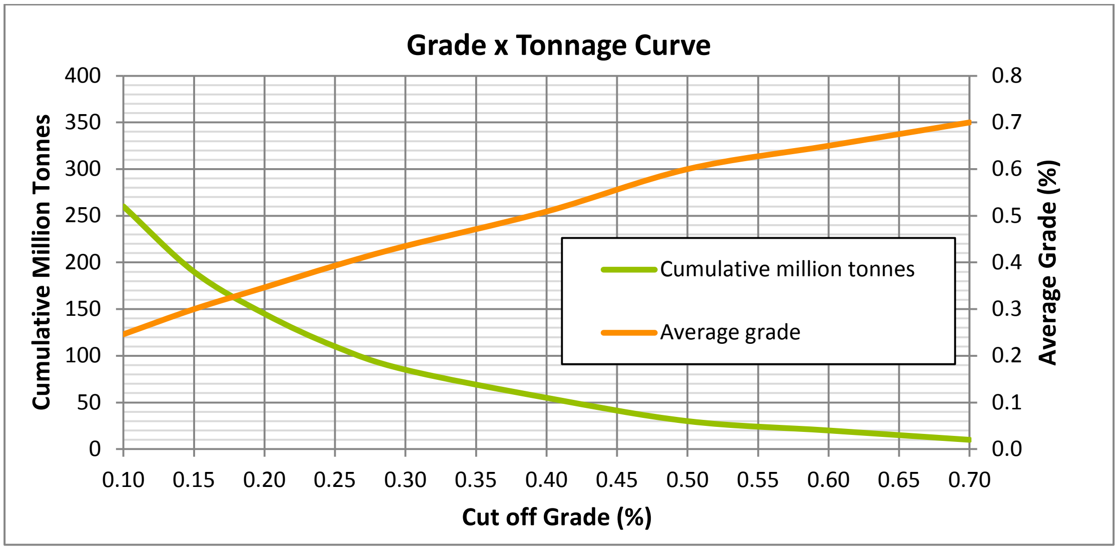


Figure 6: Grade tonnage curve for a hypothetical copper deposit

Table 2: Ore-waste break-even cut-off grade calculations

Cut-off grade calculations		**Without bulk sorting**	**With bulk sorting**	
Waste				
Mining cost	US$/t	1.2	1.2	
Processing Cost	US$/t	0.3	0.3	
Overhead Cost	US$/t	0.3	0.3	
Total Cost of Waste	US$/t	1.8	1.8	
Ore				
Mining cost	US$/t	1.2	1.25	*Increase for reject handling*
Processing cost	US$/t	11.5	8.05	*Reduce by the mass rejected from sorter*
Overhead Cost	US$/t	0.5	0.5	
Sorting cost	US$/t	0	0.4	*Sorter operating costs*
Total Cost of ore	US$/t	13.2	10.2	
Value per block				
Cu price	US$/t	6000	6000	*LME 3 Month futures at 14/1/2015*
Smelter cost	US$/t	700	700	
Sort Recovery	%	100	90	*Assume 90% recovery in 70% mass*
Plant Recovery	%	90	90	
Smelter recovery	%	96	96	
Overall recovery	%	86.4	77.8	
Cut-off grade	%	0.25	0.20	
Sorting reduces cut-off grade by	%		0.05	

The break-even cut-off grade is the grade at which it becomes economically feasible to mine a block of material. It is the grade at which enough revenue is generated to pay for the extraction, processing and selling costs (Hall, 2014). Cut-off grade is used to decide a course of action; i.e. to treat the material as ore or waste. In this example, the ore-waste break-even (where the cost per tonne of waste equals the value if treated as ore) has been used to define rock as ore or waste. By only treating material that is above the cut-off grade, only material that adds value is processed.

The base case scenario (without bulk ore sorting) has a cut-off grade of 0.25% copper delivering 110 million tonnes of ore to the processing plant with an average grade of 0.39% copper. With the inclusion of bulk ore sorting, the cut-off grade is reduced to 0.20%, changing the delineation of the ore body and pit shell and increasing the amount of above cut-off grade material, as illustrated in Figure 7. The resulting average grade of mined ore is reduced to 0.35% copper. However, bulk ore sorting upgrades this to deliver 102 million tonnes of ore with an average feed grade of 0.45% copper to the processing plant (using conservative estimates of sorter performance in which 90% of the copper is recovered in 70% of the mass). Overall, almost 8% (8 million tonnes) less ore is treated by the processing plant, but at a higher feed grade, and with 5% more contained metal than the base case scenario without bulk ore sorting.

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	0.35 %
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

Green line indicates the pit shell
Red shading indicates above cut-off grade material

Figure 7: Impact of bulk ore sorting on reporting pit and material extracted

The sorter performance and also the quantity and distribution of marginal grade ore within the deposit would have a significant impact on the results. In practice, the ore body delineation, mine scheduling, processing options and capacity should be optimised together concurrently with ore sorting options and cut-off grade selection as part of full mine strategy optimisation.

This simple high level example illustrates how bulk ore sorting could be implemented to reduce cut-off grade and increase resource utilisation based on a hypothetical deposit. A detailed study is being conducted for a known resource that is currently being mined with conventional practices and will be reported at a later date.

Case 2 – Increasing production at an existing operation with fixed plant capacity

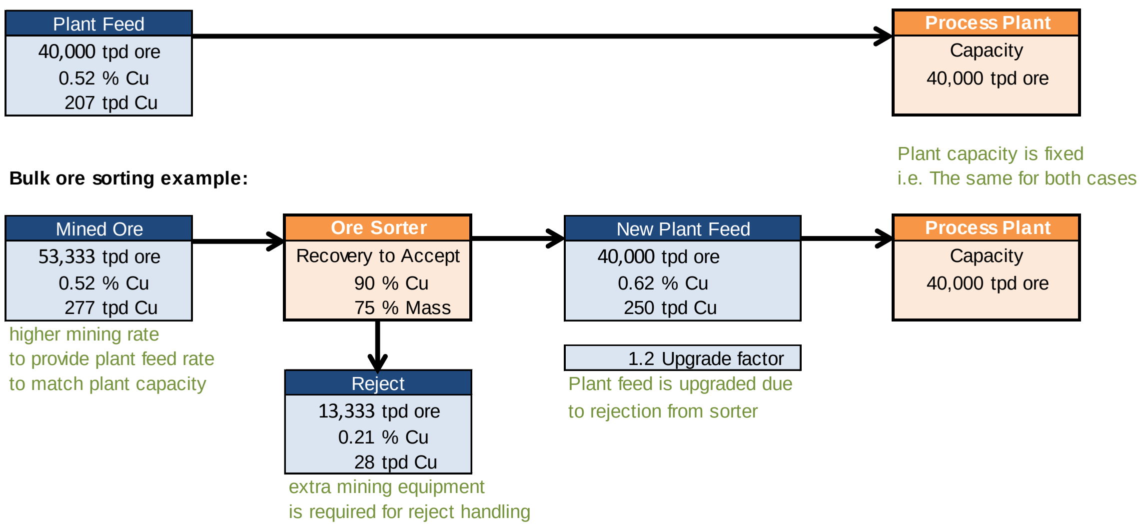
Bulk sorting upgrades the plant feed, increasing the production rate. Production and profit is brought forward in the schedule, and the amounts of ore treated (and associated costs and energy) are reduced per tonne of product.

This case considers a 200 million tonne copper deposit with a fixed plant capacity of 40,000 tpd, 0.52% copper feed grade and 15 year mine life (based on data from a feasibility study). The inclusion of bulk ore sorting upgrades the plant feed and thus increases the production rate. A higher mining rate is required to meet the plant capacity following rejection of waste by the ore sorter, as shown in the diagram provided in Figure 8.

High level Net Present Value (NPV) analysis suggests that incorporating a bulk ore sorting plant to upgrade the feed grade to 0.62% copper for this case may improve the NPV over the life of mine, see Figure 5. The NPV analysis assumes the plant capacity is fixed and the capital and operating costs of the existing mine and plant remains constant. Additional capital and operating costs are included for the ore sorting plant and associated equipment (conveyors, sensor, control system, diverter) and mining equipment for the increased mining rate and additional material handling associated with sorting.

The largest impact on NPV is that the production and profit are brought forward in the schedule, with mining completed within 12 rather than 15 years. Additionally, the operating cost of the sorter is less than a quarter of the cost of treating the rejected waste through the processing plant.

At this stage the analysis does not consider that gangue minerals are generally harder than valuable minerals, and rejecting the gangue could reduce the hardness of the plant feed and further increase the throughput and reduce energy consumption of the comminution circuits. Likewise, the increased plant feed grade could deliver improved grade-recovery performance in flotation circuits, but this has not been incorporated in the current analysis. Therefore, the benefits will potentially be even greater than estimated in this study.



Assumptions / Inclusions:
Assume plant capacity is fixed and existing plant capex and opex constant
Additional opex is included for ore sorting plant equipment (conveyors, sensor, control, diverter)
Additional opex is included for reject handling (removal and stockpiling of rejected material)
Additional capex is included for the increased mining rate and reject handling
Additional capex is included for ore sorting plant including conveyors, sensor, control system, diverter

Figure 8: Schematic of bulk sorting with fixed plant capacity

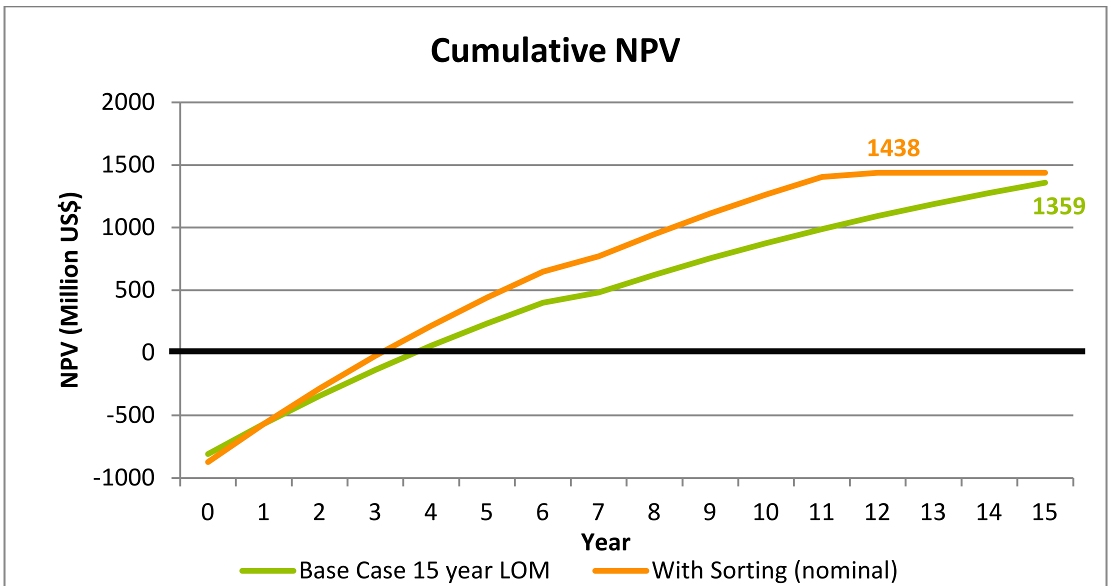


Figure 9: Impact of bulk ore sorting on NPV over life of mine (fixed plant capacity)

Sensitivity analysis indicated the most significant factor affecting the NPV results was the sorter upgrade factor, as shown in Figure 10. The upgrade achieved by the sensor is influenced by the variability in the ore as the sorter receives it and the efficiency of the sorter. Therefore, it is very important to understand the ore characteristics, variability at the measurement point and sorter performance.

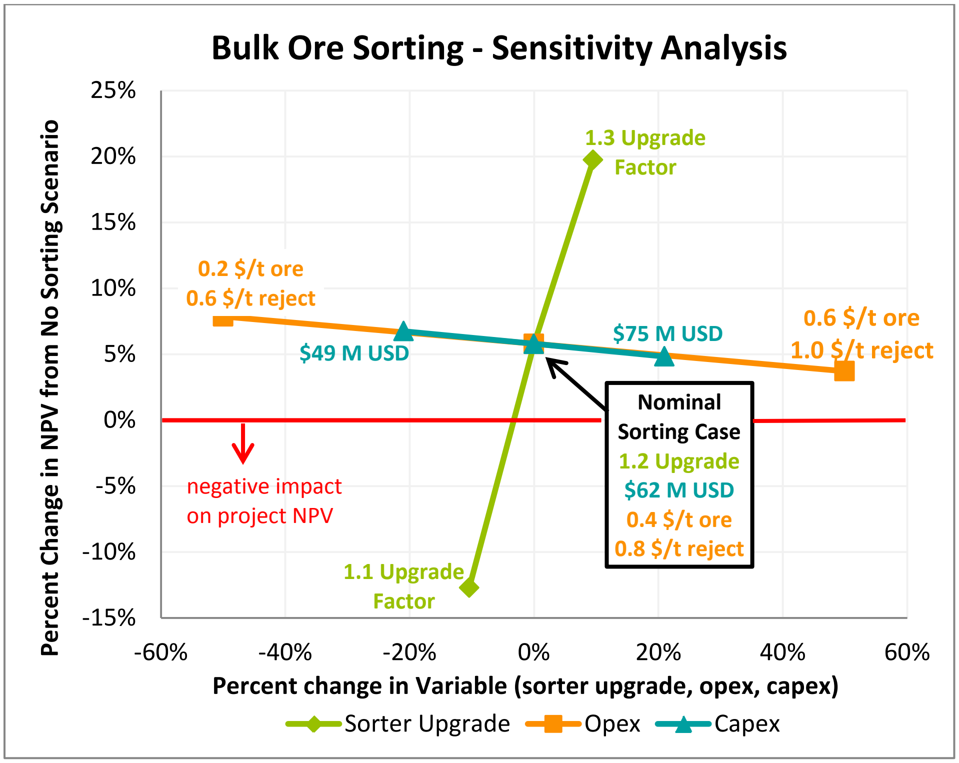


Figure 10: Sensitivity analysis of the impact of ore sorting on NPV

Case 3 – Reducing ore losses and dilution through improved grade control

Measuring grade with a bulk ore sorter enables correct allocation of ore and waste, reducing dilution and ore losses.

A mining block model and selection of material to be mined is based on grades determined using kriging (interpolation), which introduces errors. The actual grade is not known, and is often not measured before material is classified as ore or waste. This results in dilution and ore losses due to mis-classification. Blast movement, internal waste mixed with ore, inaccuracies in ore and waste boundaries, large scale (non-selective) mining equipment and logistical errors also contribute to dilution and ore loss. Measures can be taken to reduce dilution and ore loss, but it cannot be completely avoided (Ebrahimi, 2013), see Figure 11.

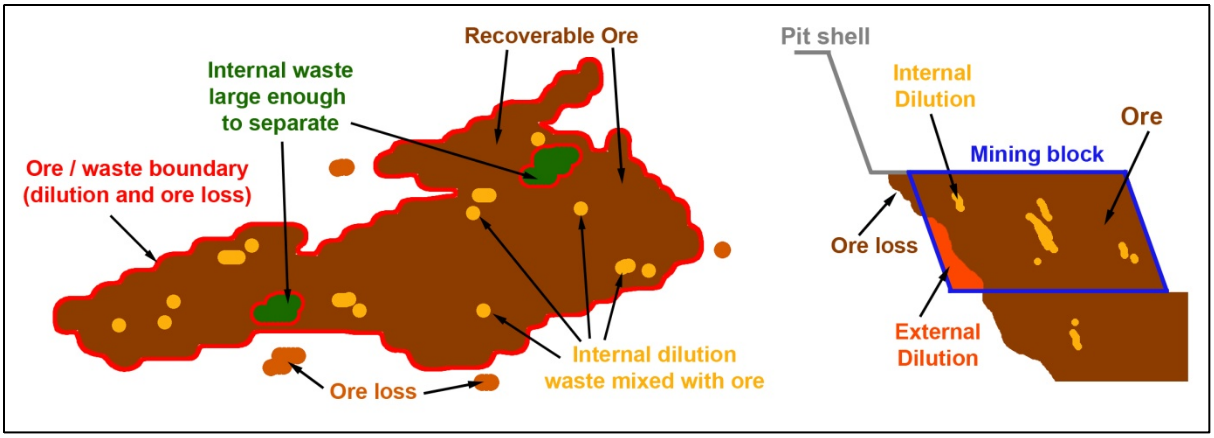


Figure 11: Schematic illustration of dilution and ore losses

Dilution can have a very significant impact on the profitability of mining operations. Dilution decreases the plant feed grade. Operating costs are increased, as a higher tonnage is treated by the processing plant per tonne of product, and the processing plant capacity is effectively decreased, prolonging the mine life. Lower plant feed grade also reduces plant recovery in many cases. Dilution also increases the cut-off grade which reduces the overall resource utilisation. Ore losses occur when ore is misclassified as waste and not processed resulting in lost revenue.

The amount of dilution and ore losses is typically not well understood as it is difficult to quantify. It is likely that it is underestimated at many operations. At Somincor, an underground copper and zinc mine in Southern Portugal, the SmartTag™ ore tracking system is used to track ore and waste. It was found that around 20% of waste was treated as ore and a similar amount of ore reported as waste prior to improved grade control practices using the SmartTag™ system (Wortley, 2013; personal communication).

Reducing dilution and ore losses represents a significant opportunity to increase profitability. For example, Prati (2014, personal communication) estimated US$29 million is lost per annum due to dilution of feed grade for an 8 Mtpa copper mine. The lost value in ore misclassified as waste is potentially much greater, as was demonstrated by the Somincor example.

A bulk ore sorter can reduce both dilution and ore loss by improving grade control. Measuring grade with the sorter will allow correct allocation of ore and waste. Only above cut-off grade material is sent to processing, improving the execution of the theoretical cut-off grade. Likewise, above cut-off grade material (and revenue) is not lost to waste dumps. Ore sorting may also reduce (but not eliminate) the quality control requirements at bench level. This has potential to increase mine productivity and reduce costs, particularly in deposits with complex mine geology and when mining near ore / waste boundaries.

Conclusion

The purpose of bulk ore sorting is to remove coarse barren material before energy and cost intensive downstream processing and handling. Fewer tonnes of ore are treated per tonne of product, reducing the costs, energy and water consumption per tonne of product. Thus, bulk ore sorting has the potential to improve the profitability and reduce the environmental impact of a mining operation.

Bulk ore sorting may be used to increase the production rate through fixed plant capacity, or reduce the required size of downstream processing equipment. Uneconomic or marginal reserves in the deposit, waste or low grade stockpiles may be upgraded making them economic to treat and improving the resource utilisation. Uneconomic deposits may become viable due to the upgrade and increased productivity following bulk ore sorting. Additionally, bulk ore sorting can reduce dilution and ore loss in mining operations by improving grade control, and could also be used to separate different ore types to treat separately. An efficient ore sorter allows selectivity on the basis of a smaller volume; for example, meters of material on a conveyor belt rather than by truck load.

The key driver affecting the economics of bulk ore sorting is the upgrade that can be achieved by the sorter (the recovery and mass rejection). Essentially, how effectively the sorter can remove the barren material while recovering the valuable components. This is a function of the ore characteristics, distribution of grade throughout the deposit, and the efficiency of the sorter, and requires extensive testing and evaluation on a case by case basis. The impact on the overall operating capital and operating costs for the operation also needs to be considered. It is likely that, at least in some cases, the additional costs associated with bulk ore sorting will be outweighed by the reduction in downstream processing costs and/or increased production.

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