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A Step Change in Mining Productivity

Time to Deliver the Promise*

Joe Pease, Stephen Walters, Luke Keeney, and Greg Shapland

ABSTRACT

The mining industry has long sought a step change in productivity by integrating operations from mine to market. While there have been some success stories, in general the promise has not been delivered due to some crucial gaps in technology and systems. Many of those gaps have now been closed, or at least recognized, meaning the tools are now available to deliver the benefits of integration.

THE MINING PRODUCTIVITY CHALLENGE

The minerals industry faces a productivity and investment crisis. The “Millennium Super Cycle” from 2003 to 2011 was an unprecedented period of growth and investment. Throughput was increased and lower grade resources were developed to meet demand. The urgency to bring production to market quickly stretched people, project, and management resources. But the “boom” ended and prices have declined, with the industry left with a legacy of high costs, declining ore quality, and less efficient operating practices. Step changes to practice and productivity are needed to sustainably produce the minerals society needs.

Groups including the Cooperative Research Centre for Optimising Resource Extraction (CRC ORE) are working with the global resources industries to reverse the trend of declining feed grade and quality through novel approaches and innovative solutions (Figures 3.1 and 3.2).

TRANSFORMING MINING PRODUCTIVITY: AN INTEGRATED APPROACH

CRC ORE was established in 2010 to address these productivity challenges. It is a large scale, industry-led initiative that brings together orebody knowledge, mass mining, mineral processing, ...
and resource economics. CRC ORE provides a bridge between technology development and site implementation, working with a consortium of global mining companies, mining equipment, technology and services providers, and research organizations. The aim is to achieve a step change in productivity by adopting an integrated, manufacturing-style approach to the production of metals from drill core to product. In particular, there is a focus on improving feed quality early in the production value chain.

The minerals industry has long sought improvement by integrating operations from mine to metal. In the 1990s, this was the driving force behind “Mine-to-Mill.” The disappointing thing was not that Mine-to-Mill failed to deliver value. The disappointing thing was that it did so successfully

![Comparison of normalized feed grades for selected world-class porphyry Cu deposits](image)

**FIGURE 3.1** Decline in feed grades for copper operations.

![Productivity crisis in Australian mining](image)

**FIGURE 3.2** Productivity crisis in Australian mining.
and yet then withered at many sites. It was widely accepted—but not as widely adopted. Even worse, many of the successful “poster” sites gradually reverted to the traditional “silo” approach of managing operations.

CRC ORE has worked to understand why those good intentions failed to deliver or be sustained. It was not because industry did not try, but rather because crucial gaps in technology and systems meant solutions were not “robust” enough to survive the operating environment. CRC ORE seeks to close those gaps to enable robust, long term, and integrated systems for minerals production.

CLOSING THE GAPS

CRC ORE believes that the barriers to integration were measurements, ore heterogeneity, integrated systems, and supporting management systems. Therefore, the industry should identify and develop solutions in these areas. Tools have to be combined, assembled, and “ruggedized” on other sites, and management and organization systems must support and “lock in” the changes.

MEASUREMENTS

A manufacturing plant controls its feed within strict limits, setting specifications and measuring to ensure compliance. In contrast, in mining the feed quality is variable. In most cases, we cannot measure quality as it enters the production process. We measure and control so many variables on a mining truck that we can operate it autonomously from the other side of the world. But we have almost no measure of the most important thing, the quality of the payload, the feed to the metal manufacturing (Figure 3.3).

Providing routine on-line feed quality measurements of coarse run of mine (ROM) ores or mill feed is technically challenging. However, ongoing developments in sensor technologies in fields such as neutron activation, magnetic resonance, and laser-induced breakdown spectroscopy offer potential solutions. In some cases, these technologies are already being used at feed belt scale in rock-based industries where maintaining feed quality specification is crucial to generating saleable

FIGURE 3.3 Measurement problem.
product, for example, cement manufacture. The next step is to prove their application and business value for bulk base and precious metal mining. Measurement of grade early in production opens new fields of possibility for coarse separation.

A medium-term vision is to sense the grade in every loader bucket or transfer point, to enable a separation decision at multiple points. This requires the development of more robust and compact measurement hardware. But the technology already exists to measure grade on conveyors. This could identify intervals of high-grade or low-grade ore that could be diverted to separate destinations. This will enable some important applications of grade engineering. An ultimate manifestation would be an in pit conveying and separating system as shown below, yet there are many less ambitious options that can be applied now (Figure 3.4).

HETEROGENEITY: FRIEND OR FOE?

Mineral deposits are heterogeneous. The common response is to attempt to smooth or blend the feed to downstream processing. This smoothing process often starts early in data collection, so even mine block models do not capture the full heterogeneity of the orebody. While smoothing makes sense once a flow sheet is settled, perversely it has also hindered the adoption of manufacturing principles in the design of new flow sheets.

CRC ORE believes that a manufacturing approach to integration must start with an acceptance of the things that fundamentally differ between mining and manufacturing—measurement difficulty and feed heterogeneity. Rather than try to eliminate heterogeneity by smoothing, the early stages of mining, and processing should embrace and exploit it. This is the principle behind “Grade Engineering™.” It means identifying and removing low-grade unprofitable materials as early as possible, whenever possible, however possible.

The concept of removing uneconomic material rather than smoothing it through plant feed is not new—it was practiced by our forebears as hand-picking; is practiced in some plants as dense medium separation, and in others as ore sorting. In a well-reported example, Bougainville Copper
upgraded sub-marginal ore by screening to remove coarse low-grade rocks, exploiting a natural preferential deportment of copper values to fines. The impact can be enormous—the dense medium plant at Mount Isa lead zinc removes about 35% of coarse and hardest feed before the fine grinding treatment process. That increases the throughput, reduces the capital intensity, and reduces energy requirement by over 40%.

Yet, it seems the principles of early waste removal are not always considered in the design phase of a mine. Many operations design the “standard” circuit of stockpile-conveyor-semi-autogenous grinding (SAG) mill-ball mills-flotation. Once selected, this circuit prefers a smoothed feed, and the materials handling and feed sizing prevents the application of most coarse separation options. This flow sheet may well be the best solution for an ore; but that can only be judged after options to exploit coarse ore heterogeneity have been examined. An interesting question is this: if your company was developing Bougainville or Mount Isa lead zinc today, would it consider a coarse screening plant or dense medium plant? Or would it just accept the higher capital, higher operating cost of the “standard” circuit?

**COARSE UPGRADING OF ORES**

Every ore is different. Different areas of the same orebody are different. Therefore, any solution must recognize that there is not a general solution, but there can be a general approach. One way to categorize and compare solutions is the concept of Grade Engineering® developed by CRC ORE. This is a toolbox of analytics and techniques to assess the potential to apply coarse upgrading to any ore. A range of possible separation techniques can be assessed, and the response of that ore ranked relative to other orebodies. CRC ORE has characterized and assessed a large database of global ores using this approach. On some sites, the heterogeneity does not support a business case; on other sites, a significant business case has emerged. The increasing database of industry studies means faster and more accurate “desktop” assessment for new operations.

Five potential coarse separation mechanisms are:

- **Induced sized deportment by preferential blasting**—for example, blast higher grade zones fine and low-grade zones coarse, then separate by coarse screening.
- **Natural size deportment**—that is, exploit natural tendency of valuable minerals to concentrate in fines; upgrade ore by screening out coarse low-grade rocks.
- **Coarse gravity separation**—exploit coarse gangue liberation by removing it before grinding, for example, dense medium, jigs.
- **Sensor-based mass sorting**—measure (or infer) grade, divert low-grade batches or conveyor intervals to waste.
- **Sensor-based particle sorting**—measure distinctive characteristic of valuable ore gangue, and eject individual particles.

CRC ORE has tested a wide range of ores and has developed protocols to place an ore on “response ranking curves” to assess coarse separation potential to each of these mechanisms relative to other ores (Figure 3.5).

Any orebody may respond to one or more (or none) of these levers, and they may combine to increase effect. For example, induced size deportment does not rely on natural size deportment but may be enhanced by it. Induced size by differential blasting will also increase mill throughput because of the finer mill feed. The most appropriate mechanism(s) will be determined by the characteristics of the mineralization and the heterogeneity of the deposit. Dense medium separation or natural size deportment will not suit disseminated mineralization. Yet, the orebody may exhibit significant variation in grade across the production bench. This could be exploited by grade sensing in belt or bucket and diverting low-grade intervals to waste. Alternatively, differential blasting can
induce a size difference between high- and low-grade zones in the pit, with the low-grade coarse fraction removed by screening. The results of a full scale site demonstration of this are depicted in Figures 3.6 through 3.8.

This technique increases mill feed grade by diverting below-cut-off-grade material. While this reduces metal feed to the mill, this can be recovered by similarly recovering small high-grade areas from waste benches. Thus, metal production rate can be maintained or increased with a higher mill

![Figure 3.5](image)

**FIGURE 3.5** Response ranking curve for natural grade deportment by size.

![Figure 3.6](image)

**FIGURE 3.6** Differential blasting. The high-grade zone is blasted to a fine size by close blast-hole spacing and high powder factor. Minimal blasting in the lower grade zone produces a coarser sizing. The high- and low-grade zones can be mined together and separated by screening.
A Step Change in Mining Productivity

feed grade. Economic streams can be generated from previously sub-marginal ore. This is a step change in productivity using simple technology—blasting, belt sensing, diverters, and screening. The technology components are available, but first the business case for various options must be assessed. Then, the components must be assembled and engineered into a robust solution. These are the objectives of CRC ORE.

![Flow sheet for site demonstration of selective blasting.](image1)

**FIGURE 3.7** Flow sheet for site demonstration of selective blasting.

![Results of site demonstration of selective blasting and screening.](image2)

**FIGURE 3.8** Results of site demonstration of selective blasting and screening.
THE NEED FOR INTEGRATED SITE SIMULATION

To support the integrated approach to minerals extraction, operations must take an integrated view to simulating, then optimizing, the entire operation, from block model to final product. Traditionally, technical models have been restricted to individual “silos”: the block model, the blasting model, the grinding model, and the flotation model. Some of those models were single dimensional, not capturing the full range of variability of ores (grade, hardness, flotation characteristics, etc.). Yet to optimize an operation, all the production models need to “talk” to each other and allow for the multidimensional nature of ore. Otherwise, the outputs of different models are put together manually, a process which is unlikely to capture the interaction between stages, and therefore will not find the optimum.

CRC ORE addressed this need by developing a value chain simulator known as the integrated simulation simulator (IES). IES incorporates the outcomes of over 50 years of JKMRC and AMIRA research, combining existing industry standard simulation models with models from diverse research and development sources.

IES is a mining simulator that integrates all mining and mineral processing activities starting from drill and blast, through loading, hauling, stockpiling, blending, crushing, and grinding and processing. It allows multiple ore types to be considered from the block model to product, and allows for the interaction between those steps. For example, IES allows operators to assess future ore sources for the effect that changes in blasting will have on grinding and how this will impact flotation. Therefore, it can be used to assess changes in the design, layout, and operating steps to optimize metal production and environmental footprint. It provides a model development environment that allows the user to access or input models that suit their specific equipment.

SUPPORTING MANAGEMENT AND ORGANIZATION SYSTEMS

The technology and techniques for a step change in industry productivity are well within reach. The next phase of the program is to assemble and demonstrate them in high value site applications.

But to achieve the value and to lock in the gains, the technology must be supported with appropriate management and control systems. The integrated approach to production must be matched with a similar management approach. Though every organization supports this principle, often existing management and reward systems inadvertently hinder it. Careful design of key performance indicators (KPIs), targets, and incentives is required to ensure that individual efforts combine to optimize the overall site, and not isolate activities into “silos.” For example, the drill and blast crew should be rewarded (not penalized) for increasing their unit cost if it increases site productivity. This principle is well understood, yet KPIs remain insidious barriers to genuine integration. Researchers, technical staff, senior management, and system providers need to work together to develop the tools and business support for integrated operations.

THE TIME IS RIGHT

The Mine-to-Mill initiatives of the 1990s showed that better coordination of activities will yield significant productivity gains. Yet, the changes were not robust enough to be maintained.

After an era of major expansion to meet the “supercycle,” the minerals industry now desperately needs to increase productivity as both feed quality and prices decline.

The tools, both technical and analytical, are now much better developed. They can now be combined to quickly assess ores and options, and in many cases to demonstrate significant improvement. The technology is simple. Further engineering and site demonstration is needed to make it robust and reliable. Then, it needs to be supported with appropriate organization and management systems.

Finally, the time has arrived and the tools are within reach to truly integrate mining operations.