Transaction Paper

Business improvement in the mining and metals industry

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Synopsis

In the mining and metals industry, business strategy demands that leaders extract more from any set of capital assets. This improvement is achieved through a combination of continuous improvement and upgrading of the assets.

Continuous Improvement involves a series of incremental changes in the workplace to stabilize the process, remove waste, and test the limits of process capability.

Enhanced Technology involves the replacement of an existing asset with a different process or equipment, to achieve a similar function in a more efficient and effective manner.

The paper compares and contrasts the two methodologies and outlines the key business considerations which dictate how and when to select one or other improvement method. The paper also addresses the implications for these two improvement methods for those undertaking R&D in support of the mining and metals business.

Business strategy

As a price-taker in a commodity industry, each mining and metals business is seeking to sustainably reduce unit costs and maximise tonnage from its capital assets. Business success is based on accessing the best resource base, and then utilising this resource at the lowest cost. This paper focuses on increasing production and reducing unit costs (Figure 1), through using the optimum technology in the most effective manner.

Mining and metals operations are capital intensive (high capital invested per unit of revenue), with a comparatively slow technological obsolescence. A measured approach to replacement of fixed assets is essential. Most sectors have relatively open access to technology through a common platform of equipment and technology suppliers.

Maximizing production, either through equipment selection or improved operational performance, is a significant component of business improvement initiatives. Sustainable reduction in unit costs, by eliminating activities that do not contribute to safe and reliable production, is also critical to business success.

These contributions to shareholder value are built on two alternative approaches:

- ➤ Continuous improvement (CI) through elimination of the multiple forms of waste that exist in every operation. Examples are: accidents; recovery losses; excess inventory; multiple handling of materials; rework and scrap; waiting time
- ➤ Investing in the Enhanced Technology to maximize: throughput; conversion efficiencies; and human productivity.

A case study

To illustrate the principles underpinning the two improvement methodologies, a case study will outline relevant examples. It is based on the improvement journey to extend the productive life of an aluminium smelter. The principles can equally be applied to other business decisions such as: fleet upgrade in an open pit mine; increasing tonnage and recovery in a gold plant; changing the mineral processing circuit; reducing the unit costs of a pgm operation; or improving safety in an underground mining operation.

In aluminium smelting, the production paradigm is set by the cell technology in the reduction lines. As the highest capital cost, the hundreds of reduction cells form the bottleneck of the plant. Technology development over the past century, has progressively expanded the electrode dimensions of the cells. Hence, at the typical current density, the production capacity of each new generation of technology has been enhanced. The dimensions of the hundreds of reduction cells, and their associated support infrastructure, are essentially fixed for the life of the plant.

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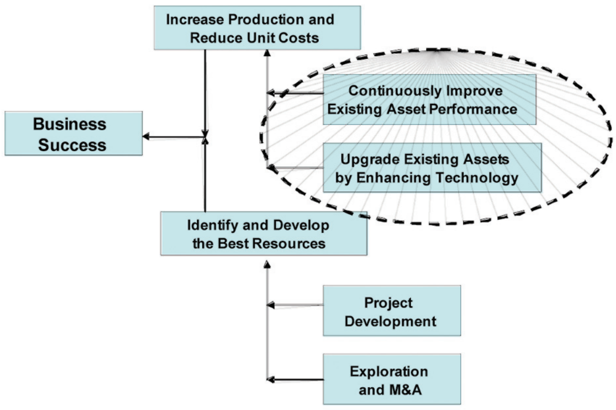

Figure 1—Asset effectiveness can be improved through continuous improvement or enhanced technology

Consider an ageing 85 kA aluminium smelter approaching the end of its long term power contract. Options were closure in several years at the end of the power contract, or to negotiate a new power arrangement together with: a new reduction line utilizing established 300 kA technology; retrofitting a prototype technology to enhance the reduction efficiency; or squeezing the most from the existing assets.

The initial decision was to redevelop the smelter with a larger cell using the best proven technology. However, after difficulties in reaching an appropriate power arrangement the decision evolved to closure. The rate of improvement achieved over these last few years was substantial. The gains during this capital starved environment, together with rejuvenated power discussions, caused a reassessment of the decision to close. The smelter is currently still in operation fifteen years later, now using a 50 year old technology base, and with most of the critical operational efficiencies matching the best available technology of today.

As one method to quantify the gains, 70 ktpa additional capacity has been created from essentially the same assets. Equivalent greenfield capacity would cost around US$350 million.

The improvement process, integrated with changes in the flexibility of work practices, broke many strongly held myths about what is possible with old equipment.

The continuous improvement journey

CI utilizes multiple small changes to processes and equipment, to remove waste and enhance throughput from an existing asset system. Many of the CI concepts had their genesis in the manufacturing industry. Lean Manufacturing[1,2] and Six -Sigma[3] are structured methodologies used to support the CI journey.

CI mobilizes the skills and experience of the hands on operational team to improve and sustain their own area of accountability. These teams can also be bolstered with the appropriate technical skills to help select, scope and implement the best CI projects.

CI relies on removal of variation, utilizing the right measures, and eliminating waste in its many forms. The CI cycle requires three steps to reach a sustainable improvement (Figure 2).

Step 1—Standardize and stabilize

An unstable process cannot be improved. Hence, standardization and stabilization are initially more important than process optimization.

The starting point is to establish a single best way of performing each routine task. This current best practice is identified, documented and aligned amongst the work team(s), creating an opportunity for all employees to contribute in their own work area.

Current best practices were developed for routine production, maintenance and administrative tasks. Each best practice described the purpose, how to perform the task safely and effectively, the scheduling, and the physical and chemical output targets. This sharing of ideas across shifts, often highlighted simpler and safer work procedures that had developed in isolation by specific crews or individuals.

In order to embed these best work practices, a job observation technique was introduced. Each crew member would observe others undertaking the tasks and discuss with them the safety, procedures and outcomes. These interactions within and between crews embedded the more consistent performance.

As one measure, the lost time injury rates in the standardized and stabilized operations have fallen to around 10% of historical levels.

Once work routines are standardized, causes of variation (e.g. breakdowns in equipment) are more readily identified. The root causes can be systematically addressed to stabilize the materials and work flows. Elimination of the root cause, rather than compensatory controls (no band aids), reduces the complexity of the operation; decreases the total work required (do it right the first time), and enables all the major measures such as variation, cost, safety, throughput, etc - to improve in unison (no tradeoffs).

Hence, the preferred hierarchy for stabilization declines from eliminating the cause to better managing the implications:

- ➤ Eliminate the cause (e.g. eliminate peak stresses which damage equipment)
- ➤ Manage the cause (e.g. use components which increase the mean time between failure)
- ➤ Intervene before failure (e.g. inspect and replace components before failure)
- ➤ Manage the consequence (e.g. reduce downtime by systemizing the repair)
- ➤ Insure against failure (e.g. add resources to address the variation when it occurs).

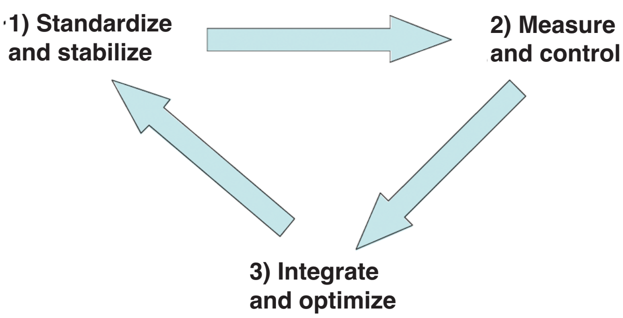

Figure 2—The continuous improvement cycle

Where necessary, the current best practice is upgraded to accommodate the new opportunities. Documentation, training and follow up with workplace observations are all essential to standardize and sustain the each improvement.

As each special cause of variation is addressed, the production system as a whole is stabilized. Emergencies become rarer, and work is undertaken to plan. Start/stop operation of equipment is eliminated thereby reducing the stress on each component of the system. Each work team can rely on a consistent feed from its internal supplier and can produce a more consistent product for its internal customer. The more predictable work pattern allows scheduled time for preventative maintenance (hence further increasing stability), and people can be freed up for improvement teams, thus further reinforcing the virtuous cycle of improvement.

The overhead cranes in the reduction lines were notoriously unreliable, but capital was tight. Since many of the daily tasks of tending the more than 500 reduction cells require the use of these cranes, work flows were frequently disrupted both within the reduction area and with flow on effects up and down stream of reduction. These disruptions also led to variation in cell condition as the time between anode setting and tapping events was often variable.

Scheduled maintenance and more systematic recording of history enabled effective root cause analysis. The resultant improvements involved replacement of worn crane rails; and air conditioning and modernizing the cranes' electrical circuits. These changes considerably improved the reliability of reduction line operations, creating a virtuous cycle of improvement in the upstream anode rodding and downstream casting areas of the smelter.

Implementing CI in an isolated part of a production chain is not sustainable. Waves of variation will flow through, overwhelming the stabilisation in any particular work area. The root cause of a particular variation may be located outside the particular work area, requiring improvement teams which overlap the relevant areas. This builds the understanding of the impact of each area of an operation on its internal suppliers and customers.

Step 2—Measure and control

If a process is not measured, it cannot be controlled.

Materials and information must flow from area to area of accountability. The production chain is a set of suppliers and customers, with measures which integrate each link of the sequential process. The mapping and structuring of these measures across the manufacturing flow is often termed SIPOC (Supplier, Input, Process, Output, and Customer illustrated in Figure 3)

Good control demands a manageable number of agreed measures between work areas, focused on the important specifications.

Starting with the customer, important measures are identified, each with a clear business consequence, if the process is outside the specification limits. The measures provide the basis for developing a process control plan, which in turn dictates a set of preferred inputs from its internal supplier. And so, the development of measures and control plans can be progressed back up the supply chain. As process suboptimization can occur where costs or quality have been optimized, independently of the impact on customers and suppliers, the discussion of comparative costs and benefits between the teams allows adaptation to maximize the overall business value.

Commencing SIPOC at the customer end of the chain encourages the removal of variation at the input of any process, rather than building the additional cost and complexity of compensatory controls. In this way, the natural variability of the orebody is addressed as early as possible in the production chain.

Visibility of the measures in the workplace is important to enable team leaders and members to rapidly absorb the status of a process. Control limits dictate when to (and when not to) intervene in a process. Measures also enable root causes of variation. (e.g. by using the statistical analysis tools to link cause and effect) to be identified.

Variability in time and materials flow requires special attention. The natural inclination is to maximize output in a given period as time is a resource which cannot be replaced. However, overproduction in an isolated section simply builds inventory, an expensive form of capital. These inventories hide the root causes of unreliable equipment, and add costs due to the associated multiple handling.

This control of (not maximizing) production rates is a fruitful area for improvement for front line leaders. Manufacturing plants use the central conveyor to regulate the drum beat of their process, but the mining and metals industry has set up a discontinuous batch process with the maximum production flow set by the process bottleneck. There is no ready means of enforcing the harmony in the upstream and downstream production processes. For an interdependent sequential process it is often faster to go slower.

During tapping, the metal was occasionally contaminated with bath, which accumulated in the transport crucibles. The cleaning of each crucible was condition based, and carried out in another part of the plant. The bath accumulation results from entrainment, particularly in the latter part of the

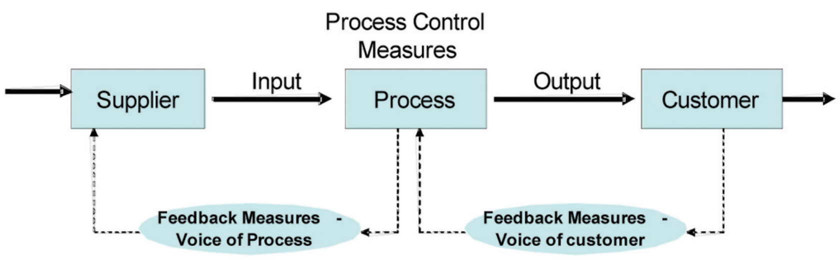

Figure 3—SIPOC-Process measures and utilized to optimize workflows across areas of accountability

tapping cycle where the metal bath interface is close to the height of the tapping pipe. Visually displaying the data on bath accumulation allowed each tapping crew to slow their rate of tapping. With lesser accumulation of bath, the cleaning crew was able to reduce the average volume of bath contamination in each crucible. The volume gains were sufficient that an extra cell of metal could be tapped into each crucible. This in turn freed up sufficient time to slow the tapping process even further.

The timeliness of a measure enables an intervention to the actual process, not what was happening when sampled a few hours ago. Online measurement has enabled much better process control and inputs to automation.

However, ready access to data can also encourage interventions where a process is operating within normal variation, thereby potentially creating additional variation. Until the purpose of each measure is understood, the control and specification limits are established with a standardised response plan, the full benefits of online measures will be difficult to capture.

The operational measures used to control the process cascade upwards to business performance measures. This integration between the process measures (what is important for maintaining material and work flows), and the vertical measures (what is important for the business on a monthly or yearly basis) provides the context for a person's role in the success of the enterprise. Sub optimization to meet a single dimensional goal can be avoided, and people in different areas can work as a part of a larger harmonized team.

Step 3—Integrate and optimize

Waste can be eliminated from a stable system.

Some waste is eliminated automatically in a stable system (e.g. accidents) but other forms (e.g. double handling, scrap, waiting time, insurance resources) must be consciously removed to sustain the improvement. As an example, excess stockpiles or crew sizes simply hide the root causes of equipment breakdown and encourage ongoing inefficiencies. This progressive removal of waste uncovers the next set of opportunities to improve the materials and work flow.

The linkage of process and business measures, highlights business leverage areas for improvements. Examples of specific business leverage points are: the bottleneck of an integrated production system; the efficiency of a high cost process; the performance of a hazardous task; the on time delivery of quality product; and the reduction of hazardous emissions. These leverage areas need to be specially targeted for improvement, as too many parallel efforts to change process capability can actually take the overall system backwards, as each individual change will cause variation elsewhere.

As the variation is reduced, the leverage process can be moved closer to the preferred output without breaching the upper specification limit (Figure 4). Therefores, process throughput (or any other beneficial dimension) can be increased.

As the capability is increased, the operational manager must establish whether the upper specification limit is real, or simply someone's comfort zone expressed as a limit. Simply pushing existing assets their operating capability exposes a risk of catastrophic failure, but some 'well known constraints' turn out to be mythical. The Six Sigma methodology[3] provides guidance on the design of experiments to test these critical specification limits.

Every cell in a reduction line operates at the same current and the maximum amperage reflects the condition of the worst cells. Reducing the variability enabled improved current efficiency and cell life at fixed amperage, but the impact of increasing current density above the industry norm was uncertain. A booster rectifier was introduced to the end of one reduction line to trial increased current in a small cohort of cells, without risk of losing control of the whole line. As the current was increased, changes to operating procedures and equipment design were required to stabilize the operation in the trial cell cohort. Once developed, the amperage on the remainder of the line could be converted to the new procedures. Then the cycle of establishing stable operation on the main lines, and trialing a higher amperage would begin again. This approach has enabled increases in current density to almost double metal production in 15 years. Cell life, current efficiency and power efficiency have all improved.

The capital intensity of the mining and metals industry means asset throughput is critical. The three components of Overall equipment effectiveness (OEE) of the bottleneck process; yield, utilisation, and throughput rate, must all be maximized (the OEE of a non bottleneck process cannot be increased except by removal of assets). Examination of the causes of variation in each of the factors contributing to OEE, provides focus on where and how to improve overall plant productivity.

The increase in metal production from the smelter meant that casting capacity was becoming a potential bottleneck in the overall system. Instantaneous casting rate was limited by the heat extraction from the mould, and yield was already approaching 100%. The downtime required for maintenance was commensurate with the tasks required, and so the initial response was to consider an additional casting station at a cost of around US$50m. However, examination of OEE illustrated a production gap after shift change when the casting crew was waiting for metal delivery to prepare the alloy in the furnace. In reduction, the tapping crew was getting into their production rhythm at the start of shift. This variation was easily resolved by offsetting shift patterns, so that casting could be maintained throughout the day using the existing metal deliveries and furnaces.

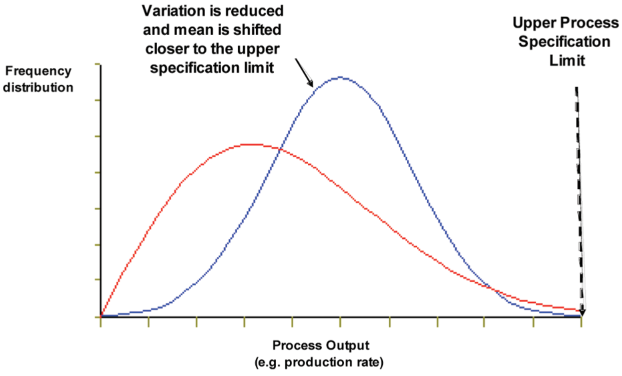

Figure 4—As variation is reduced the process mean can be increased

The capability of a critical process can be increased until the equipment or process reaches a true technical limit. This limit is characterized by an increase in variation that more than offsets the advantages of increased throughput. The technology of the equipment or process then needs to be addressed to continue the improvement journey.

The CI methodology appears straight forward, and has transformed the manufacturing industry. Most mining companies have engaged in at least part of the CI journey, but many have foundered in the journey due to decisions that seem counterintuitive to the traditional approaches to mining and metals. A few examples are:

- Standardized work is more important than heroic performance
- CI is not sustainable in isolated parts of the production chain such as business leverage points
- Critical measures should be visible in the workplace not in computer systems
- Optimising 'individual measures' is often to the detriment of the overall system
- Equipment throughput should be stabilized before being accelerated
- Capital should be the last alternative to increase capacity
- The variability of the orebody must be actively managed, early
- Waste comes in different forms:
  - 'Just in case' inventory
  - Isolated periods of record production
  - Adjusting processes that are 'in control'.

The enhanced technology journey

Ultimately, enhancement of technology underpins all the industry improvements in efficiency, and results in the long term price declines of commodities.

The initial design of any integrated system of assets sets the paradigm for its operating life. Decisions during initial design and construction are taken with limited knowledge of the resource, or the future technological advancements in equipment, or the future evolution of the market. Opportunities to improve on the initial design are expected.

Unlike CI, improvements through enhanced technology are best made through a focused and well structured design and implementation team, working outside but in close consultation with the operating team. This team structure enables the specialist skills and systems required in equipment definition, procurement, construction and commissioning

Where equipment has a finite life (e.g. haul trucks) or rapid technological obsolescence (e.g. personal computers), every replacement cycle provides an opportunity to evaluate new technology. Also, when the fixed equipment is limiting the efficiency or throughput of an overall production system, new technology needs to be explored.

The resulting investment may be:

- like for like replacement to increase asset reliability
- improved measurement and control systems to utilize the asset more effectively
- updated or larger technology to enhance process capability
- alternative chemistry or physics to achieve the function in an alternative process e.g. resin in pulp for uranium recovery, or use of high pressure grinding rolls.

Reduction line off gas has a fluoride content which must be captured to protect both the working and ambient environment. Better hooding practices improved the workplace environment, but the ducted off gas of the smelter was being treated with an older wet scrubbing technology. Despite numerous efforts to improve the contact efficiency of the wet scrubbers, emission levels to the ambient environment remained well above those achievable with dry scrubbing (adsorption onto the alumina feed to the smelter). Investment in state of the art dry scrubbing technology cut the smelter emissions to world class levels, reduced the smelter's aluminium fluoride consumption, and reduced the total power consumed in scrubbing, allowing extra power for metal production.

Whilst new technology always holds out the promise of superior performance, there are some complications to be managed.

The new equipment must operate within the overall production system, and the system adapted to the new technology. This mutual accommodation is often a factor in reaching the full capability promised by the new technology. The capacity of the new technology may be also be limited by constraints elsewhere in the system. Examples abound where new equipment is justified on additional tonnage, only to find that the bottleneck moves to the next point in the chain with only a small increase in overall production. Ideally, the new equipment will have adequate capacity for future production creep, but be operable initially to maintain a stable materials flow. This eliminates start-stop operations, and allows future increases without significant changes in work practices.

Once constructed and commissioned, the operational enhancement becomes part of the overall system of assets, to be further stabilized and continuously improved.

The hierarchy of improvement

CI and Enhanced Technology are indeed complementary improvement methods (Figure 5).

In the long-term, failure to invest in enhanced technology will mean lost competitiveness. In the short-term capital must always be rationed to provide an acceptable return to shareholders. When should the lower risk, but potentially slower, CI route be followed, and when should scarce resources be refocused to introduce enhanced technology?

To standardize, stabilize, measure and control, and remove the waste associated with excessive variability, is essential for both CI and to successfully scope, design, and commission enhanced technology. Any mining and metals business which does not have a structured approach to CI is missing a substantial business opportunity.

However, as the business critical processes approach their upper specification limits, the choice of resource allocation becomes more difficult. If the choice is to enhance technology, there is an integration risk into the existing system? If the equipment is pushed beyond its specification limits, there is a possibility of process disruption.

The choice requires a calculated view on the financial rewards and associated risks (Figure 6).

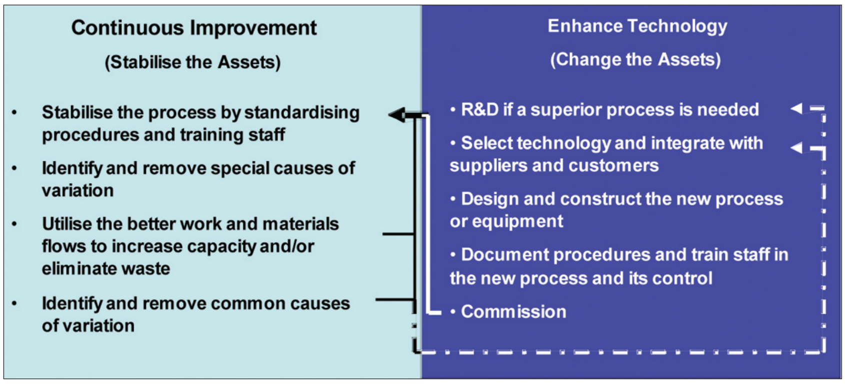

Figure 5—CI and enhanced technology are mutually reliant

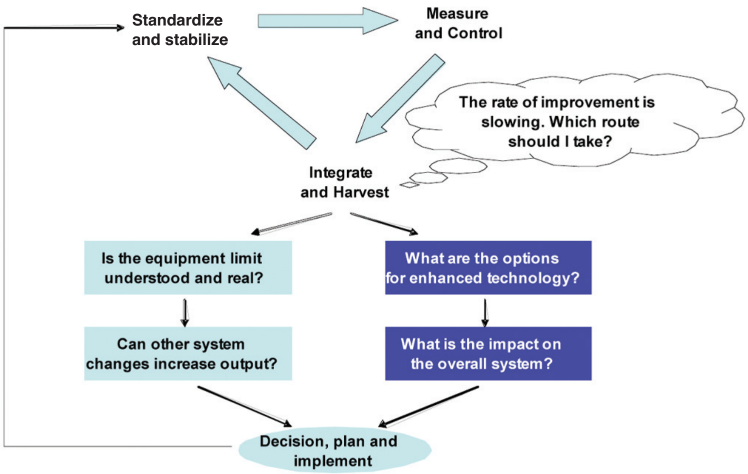

Figure 6—Changing capability requires assessment of risk and reward

Financial measures (NPV and IRR) are well established. However, the validity of the underlying assumptions and the option value of a strong competitive position require attention. Indeed, the financial evaluation between CI and enhanced technology faces two difficult questions.

Firstly, will the promise of new technology actually be achieved? The benefit is the enhanced capability of the whole asset system, not the independent capability of the new equipment. Thus, to evaluate the NPV, the next capability constraint in the overall asset system must be known. For example, if the principal financial benefit is through increased production, the next bottleneck in the system will set the capacity. Even in a stable system, these secondary constraints are difficult to identify and quantify.

Secondly, how far and how fast can the existing asset performance be improved? The constraint to progress must be understood—e.g. project leadership and resourcing, or project scope, or a technical limit. Benchmarking provides some guidance. Stable operational periods identify the available headroom. The rate of draw down of inventory during a 'good run' is another guide to ultimate capability of a particular section of a plant. External benchmarking provides information on the performance achievable by other comparable operations. Such benchmarking also promotes the identification of an improvement pathway.

Risks are less readily quantified, albeit that a number of risk management processes have been established in the industry: stagegate processes; change control procedures; and expert teams to develop risk ranking and management plans.

The cash flow (large up-front capital expenditure) and the lack of operating experience, mean the downside risks of enhanced technology are usually greater. To compensate, the anticipated financial returns should be higher. This focuses enhanced technology application towards the business leverage areas—i.e. it must achieve significant benefit to one or more of business continuity, revenue enhancement, and cost reduction.

Given the interdependence of CI and enhanced technology, and the necessity to manage both competitiveness and risk, there is a natural hierarchy to guide improvement efforts.

For all operational and administrative activities, implement the ongoing CI cycle:

- Standardize and stabilize each area of the operations
- Implement SIPOC to link areas of accountability
- Eliminate the waste exposed by the more stable process.

Then identify and focus efforts on processes and equipment that offer business leverage

- ➤ Upgrade measurement and control procedures to further reduce variability
- ➤ Move the process incrementally closer to the known specification limits
- ➤ Understand, benchmark, and challenge the constraining specification limits.

Then, for those assets that are approaching their technical limit:

- ➤ Evaluate enhanced technology to address the bottleneck/leverage process
- ➤ Design and implement the project in the context of the existing system.

Research and development of new technology

In parallel to managing today's operations, businesses must create their next generation of competitive advantage. Research and development (R&D) to support effective CI and the development of Enhanced Technology are fundamentally different in nature.

CI is based on access to data to eliminate variation (measurement, data management, control, and automation) and to test existing specification limits (process modeling)

Development of measurement and control systems has underpinned much of the recent industry improvement. Online measurement enables timely and consistent operational decisionmaking. Automation provides a consistent response to a given input, something that humans are not naturally adept at doing. Extensive data management systems facilitate root cause analysis, underpinning continuous improvement through techniques like Six Sigma. The exponential development of computing power has also opened opportunities for condition based process interventions to reduce the probability of catastrophic failure, with its consequential impact on the whole production system.

The number of individual reduction cells necessarily limits the measurement and control equipment installed on each cell. However, the high frequency voltage noise for each cell is readily accessible and offers an online indication of the cell condition. Cells operating outside of the expected level of noise were flagged to target diagnosis and intervention by a specialist operator. This simple control system to treat exceptions, combined with more regular and consistent performance of routine work, underpinned the virtual elimination of anode effects (starvation of alumina content at the cathode), increased current efficiency, and provided a basis to increase current density without adverse effect on the cell.

As the sophistication of the data analysis has increased, additional information has been inferred from the voltage signal, further enhancing the diagnostic capability. Despite being 50 year old technology, the cells now run at comparable current efficiencies and only marginally lower power efficiencies than modern cells. Their current density is 50% higher than most of their modern counterpart technologies, making up in part for their small physical size.

Ongoing opportunities for superior measurement, control and automation are substantial, particularly through separating people from damaging energy, and automating repetitive tasks which require limited human discretion.

Effective scoping of R&D to support CI can greatly enhance its effectiveness

- ➤ Is the business leverage sufficient to justify the R&D project
- ➤ Does improved control require more consistent, timely, or precise measurement
- ➤ Are the cause and effect of process variation understood
- ➤ Are the specification limits of the production system understood?

The use of R&D to replace existing equipment or processes with enhanced technology is a more open field. The slow rate of technological obsolescence in the industry reflects the challenges.

To successfully develop any new process or equipment, the accumulated benefits must justify the investment in concept development, design, construction and early operations. The cost of the R&D may be modest but the technology gains are uncertain and business calculations are indicative at best. The implementation cost is increased by the bespoke engineering design. And finally, the investment must carry a margin to compensate for the risks. It is insufficient for the innovative new process or equipment to be better than the status quo. It must offer very significant advantages, and be available at the right time for a specific application, and be sufficiently developed to manage the interface issues that arise during its initial application.

The cathode of aluminium reduction cells is a metal pool of variable height, which circulates in response to the current and magnetic fields present in the cell. Molten aluminium is tapped every 24 or 36 hours.

Titanium diboride is wetted by aluminium, and for many years a composite cathode containing titanium diboride and covered with a thin layer of aluminium has been under development. A slight inclination in such a cathode allows the freshly produced aluminium to drain into a sump at the end of the cell, enabling a narrow anode current distance, with a 15 to 20% reduction in power consumption. At the time of the smelter redevelopment, several full scale prototype drained cathode cells had been demonstrated, albeit with less than acceptable cell life. Despite the financial and environmental attraction of such energy improvements, the R&D to convert this promising concept into a robust and commercially viable design is still underway 15 years later. The complexity of the system, cathode wear, heat balance, cell management practices, makes retrofitting into existing smelters difficult. The investment in such a novel technology in a new smelter would be a high risk option.

R&D to create new technology can benefit from attention to project scope.

- ➤ Do the anticipated gains (relative to commercially proven alternatives) justify the combined cost of the R&D and the consequent capital expenditure
- ➤ Does the R&D fully enable industrial application of the concept
- ➤ How can the risks of the initial application be minimized (modeling/piloting etc)
- ➤ Where is there an application which urgently requires the enhanced technology?

It is evident that whilst new technology underpins long term progress in the industry, it requires adventurous ideas offering step improvements, and considerable strategic support.

Conclusions

Leaders in the mining and metals business are faced with an ongoing dilemma: namely, to continuously improve the existing asset base, or to seek more rapid progress through application of enhanced technology.

Standardizing and stabilizing, reduction of variation, and removal of waste from existing equipment and processes, is a prerequisite to success with either improvement pathway. The tools to achieve this continuous improvement are well established, but frequently require a counterintuitive approach to those typical in the mining and metals industry.

To further enhance business leverage requires a conscious risk/reward tradeoff to either operate equipment beyond its existing specification limits, or replace it with an inherently superior technology.

The effectiveness of R&D can be significantly enhanced by improved project scoping, to support both forms of business improvement.

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