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LESSONS FROM MANUFACTURING for MINING AND MILLING OPERATIONS and OTHER CONTINUOUS OPERATIONS

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BACKGROUND

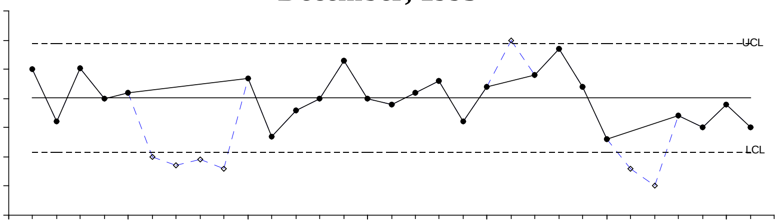
Several mining operations have learned valuable lessons from the manufacturing sector. Here two case studies are considered. The first is from Leinster Nickel Operations in Western Australia. The second is from MIM in Queensland. In both cases these operations learned that conquering variation in the early stages of the process paid significant benefits, despite the fact that they took quite different approaches towards the same objective.

Although these case studies are for mining and metallurgical operations, the same lessons apply widely, especially in continuous operations.

LEINSTER NICKEL OPERATIONS CASE STUDY

The chart at Figure 1 shows the percent of nickel metal recovered from the ore (yield) from the metallurgical plant at Leinster Nickel Operations during December 1995. The scale has been omitted to protect the confidentiality of the data. This process is out of control, a situation that was later to be corrected. Many skilled and hard-working people had given their all to optimise this plant, only to discover that improving an unstable process is extremely difficult. When a process is unstable, causal relationships are clouded by the excessive "noise" in the data. Without solid cause and effect relationships, improvement will necessarily be slow.

FIGURE 1
AN UNSTABLE NICKEL PRODUCTION PROCESS
Daily composites - percent nickel recovered from ore
December, 1995



At the time Leinster Nickel Operations was an element of WMC Resources. It is located north of Kalgoorlie in Western Australia. The operation had two mines and a metallurgical plant that produced a nickel concentrate which was shipped to Kalgoorlie where it was smelted into nickel matte. The operation had a long history of unsatisfactory performance. A large part of the reason for this was the difficult and highly variable mineralogy of the ore itself. Recovery of nickel from the ore was low when compared to similar operations, costs were high and tonnage output was less than satisfactory.

In mid-1995 Peter Smith was appointed as Resident Manager. Peter hailed from the Eastern Australian coal industry, and Leinster was a hard rock mining and metallurgical operation. There were those who cited the new Resident Manager's lack of experience in hard rock operations such as Leinster and who doubted his ability to successfully manage the business, let alone improve its productivity and profitability. However, the primary underlying problem at the metallurgical plant was instability, something the new Resident Manager understood better than most.

Apart from Leinster's operational difficulties, the metallurgical plant was without a manager. Rather than having the position filled with anyone other than a manager who had a sound understanding of variation and systems thinking, it was left vacant whilst the search for a suitable candidate continued. For several months the new Resident Manager undertook most of the metallurgical plant manager's duties himself.

Stabilise First

Peter Smith knew better than to try to attack directly the production, metallurgical and financial problems at Leinster. The first priority in his push to improve stability was to improve the reliability of the plant. Then in January 1996 a single-minded campaign to stabilise the metallurgical operations was commenced, followed by work to further reduce variation in all aspects. Experience from manufacturing demonstrated that the first step should be to stabilise the processes after which time the metallurgists and other technical people would be better able to isolate and enumerate the causal relationships. A manufacturing approach demanded that work commenced upstream, with the ore itself. World class manufacturers achieve brutal uniformity in inputs. Also, operator to operator and shift to shift variation was addressed throughout the plant. Across the entire site, a flow charting program was initiated, to help people understand the systems approach being introduced. Again, many doubted the wisdom of this approach; it was unconventional and, at least initially, did not focus directly on technical issues.

Start at the Start

A lesson Peter Smith learned from world class manufacturers was that for so long as the ore fed to the concentrator was highly variable, that good process control and high recoveries would elude the operation. He had two mines, and both contained complex orebodies that varied widely in grade, mineralogy and hardness. His initial studies allowed him to simplify the characterisation of the ores by breaking them into four basic types, two from each mine. He began by campaigning these ores through the concentrator, so that at any given time, only one ore type was being treated.

The results were almost immediate. The plant stabilised quite quickly, except for the occasional breakdown. Recovery of nickel from the ore rose significantly. Production costs fell and tonnage throughput rose. For the first time in many years the operation was performing above forecasts. The results showed that reduced variation led not only to improved quality, but also to higher output and lower costs. The contribution of the maintenance people in improving the reliability of the plant should not be overlooked. Also, Perseverance mine, under the leadership of Mr. Tim Lehany and Mr. Ross Carpenter, had been redeveloped. New mining approaches created to suit local conditions were starting to pay dividends in the form of additional tonnes of ore. This extra throughput to the concentration plant helped to further reduce unit costs.

The next step was to create blended stockpiles of all four ore types. This was done so the harder ores could assist metal liberation from the softer ores in the SAG mill. Again, recoveries improved and throughput capacity increased.

Many people contributed in various ways, but the breakthrough was created when the plant inputs were stabilised. A metamorphosis had been precipitated at Leinster. Two further events then roughly coincided to add impetus to the project. The metallurgists, now able to see "signals" through the much reduced "noise" of random variation, developed an improved ore blend to achieve even greater uniformity, and a manager for the concentrator plant, Mr. Trevor Watters, was appointed.

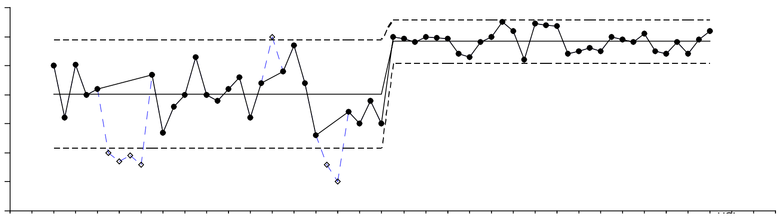
Trevor Watters was an experienced operations manager already attuned to the benefits available by reducing variation and better management of systems. He hit the ground running and soon the improvement projects identified outnumbered the number of people available to undertake the work. The staff of the metallurgical plant soon learned not to propose a recommendation not demonstrated by sound data and effective analysis.

The Metallurgical Plant was the first to convert its daily report from a tabulated format to a series of control charts. The managers and metallurgists learned that everything we were taught about statistics, from simple calculation of average and standard deviation to complex statistical models, **assumed** stability. When the data are not stable any conclusion drawn from analysis of that data must be regarded as highly suspect.

At Figure 2 is a chart showing the same process at Figure 1, before and after the transformation of the metallurgical plant. A six month period during which the four ore types were campaigned separately through the plant is missing from the middle of the chart. Scales have been omitted to protect the confidentiality of the data.

FIGURE 2
TRANSFORMATION AT LEINSTER NICKEL OPERATIONS
Daily composites - recovery of nickel from the ore

Before.....Dec '95 After......Jun '96



Further Benefits

Another significant benefit brought by stability and reduced variation is improved predictive ability. This results in better assessment of capital projects, improved allocation of capital for maximum leverage, and confidence that the predicted improvement will actually eventuate once the capital has been expended. One of the major reasons so many capital projects fail to deliver the promised financial rewards is that the initial cost/benefit studies were undertaken with unstable data. Again, any conclusion drawn from unstable data should be regarded with suspicion. It is possible to draw conclusions from unstable data that are quite different to those that would have been drawn from stable data, a fact most Chief Financial Officers are able to confirm when they compare benefits predicted to actual benefits gained from capital projects over several years.

Also, as Mr. Trevor Watters noted, the reduction in variation now allowed his operation to further increase output with less capital expenditure than was previously estimated. He pointed to many operations that attack problems similar to those Leinster was experiencing with capital expenditure. Even in those cases where the process improves significantly, his attitude is that if the situation could have been improved by reducing variation, the capital has been wasted. In his own words:

> *You don't attack metal losses and similar problems linked to process variation by injecting capital. This is best done by better process management to stabilise the process and reduce variation as far as is possible. Then capital projects can be better targeted and a higher return on capital invested is achieved.*[(1)]

Statistical process control in continuous operations brings more challenges than are normally found in repetitive manufacturing. Usually, continuous operations complicate the relationship between variation within subgroups and variation between subgroups, and lack of sub-group integrity is common. All managers and technical folk at the Leinster plant received training in control chart theory and practice, with particular emphasis placed on those aspects unique to continuous operations.

Leinster Nickel Operations never claimed to be the perfect metallurgical business. All Leinster's managers were aware of the significant challenges that remained in a business that became tougher and more competitive each year. Nonetheless, Leinster is an excellent example of what can be achieved by focussing on stability and reduced variation before tackling the other technical and production issues. In only a few months Leinster improved its financial performance by $35 million per year. Recovery of nickel rose, throughput capacity rose, metal reporting to tails was reduced, metallurgical aspects were better understood, a host of new projects was spawned, and both operational and financial performance became much more predictable from month to month. All this was achieved in months, not years, and without capital expenditure.

MT.ISA MINES CASE STUDY

Introduction

Over many years Mount Isa Mines made a huge commitment to process control in milling, but with disappointing results. One of the key differences with manufacturing was the degree of variation in plant inputs. Ore characteristics can vary widely across the deposits, and significant uncontrolled variation was being introduced to the concentrator circuits.

Ore from the Mount Isa and Hilton silver-lead-zinc orebodies is treated in the lead zinc concentrator to produce lead concentrate and zinc concentrate. The mineralogy of Mount Isa ores is complex. As the operation found itself treating largely remnant orebodies this complexity increased and performance of the metallurgical plants suffered. The concentrators were able to maintain a reasonably steady concentrate grade, most of the time. However, the price of achieving this was widely varying and generally poor recoveries. Any attempt to increase recoveries caused wide swings in concentrate grade and subsequent losses at the smelter. Because these smelting losses were greater than the potential recovery improvements the metallurgists had resigned themselves to wild swings in recoveries as an inevitable cost of maintaining reasonably steady feed to the smelter.

An Emphasis on Process Control

Like most metallurgical plants, MIM had placed great emphasis on process control technology. For twenty years they had a specialist Process Control group. A key objective was to stabilise operations and to make them independent of operator judgement. As the authors of the MIM paper at Reference 2 stated:

> *So we measured and controlled everything we could - we had flow and density meters in grinding and key flotation streams; pumpbox level and variable speed pumps in all applications; metering and control of all water additions, flotation air additions, reagent additions and froth depths; and a 26 stream On Stream Analysis system. Operator decisions were made from a centralised control room, and were carefully controlled and analysed via comprehensive log sheets and data trends.* [(2)]

Process control is at its simplest and most effective in those manufacturing operations that ruthlessly control all inputs. Process control frequently fails, even in manufacturing, when inputs have significant variation. There is a strong correlation between the level of variation in the inputs and the effectiveness of process control, regardless of whether this process control is undertaken by operators or by instruments.

Many metallurgical plants allow the inputs to vary widely, and then struggle to control this variation in the process. At MIM and at other places, the results were predictably disappointing. The metallurgists were faced with a decision. Either they must control the variation at its source, or they must continue to apply ever increasing levels of complexity and sophistication to process control approaches. The major problem with the latter option is that it is extraordinarily difficult to obtain on-line measures of the ore that give any hope for success. Also, the configured and interactive nature of so many variables was so complex that effective process control of complex orebodies seemed an impossible dream.

1995 saw the appointment of a new site GM with a manufacturing background at MIM. Following a visit to the lead zinc concentrator he declared it totally out of control. Moreover, he was unwilling to accept that wild swings in recovery were inevitable and wanted to know what the metallurgists were going to do about this situation. The hunt for new ideas and approaches was commenced.

In 1996 the GM of the metallurgical plants engaged a consultant with experience in both mining/metallurgical and manufacturing to examine the situation and to recommend a way forward. His statistical analyses showed the process to be so unstable that in many cases the control limits for key variables were meaningless. His report stated that for so long as the inputs remained as variable as they were, good process control and improved operating and financial performance would be impossible. He made two key recommendations; to improve the cooperation of the mines and the mills in pursuit of a single set of financial objectives (Mine to Mill or systems thinking) and to reduce variation in the inputs to the metallurgical plants. [(3)]

Addressing the Underlying Variation

After exhaustive analysis, MIM addressed the input variation issue in two stages.

- **Stage 1.** Remove the low grade ore sources that were not economic by themselves. When the three lowest grade sources were removed, the degree of variation in ore was reduced by almost 40%.
- **Step 2.** Schedule or blend the remaining profitable sources so that the plant gets a consistent ore type for predictable campaigns.

The very low grade ore constituted 25% of the feed. There was a tendency to believe that things would “average out” in the metallurgical plants. At MIM this resulted in “average” metallurgy being used to financially evaluate orebodies, rather than actual metallurgy for each discrete orebody type. This resulted in ore that actually resulted in losses being mined and treated.

The first stage, eliminating unprofitable ore, was the main focus at MIM. It has given significant benefits without capital expenditure or increasing operating costs because the elimination of these low grade ores significantly reduced variation in plant feed. The second step, blending/scheduling can be problematic, especially when real estate is in short supply, but progress was made. As was the case at LNO, consistent plant feed requires blended ore stockpiles for campaigns of about one week.

Implicit in the approach used at MIM for many years was the assumption that concentrator metal recovery is the approximately same for all sources because it assumed "average" metallurgy for all sources. This may have been a reasonable assumption when MIM was mining relatively homogenous ores, but it proved meaningless for the highly variable remnant orebodies. The metallurgists discovered that many of the low grade orebodies would never have been justified if the correct metallurgy for each ore type had been used, and if they had been attributed their true production cost rather than a low marginal cost, which underestimated the true cost.

About 30% of the orebodies were removed from the mining schedule because they could not be shown to be profitable when each ore type was examined separately. A similar percentage of operating costs was also removed. For a long time MIM had scaled the orebody to suit the operations. Their new approach demanded that they scale the operations to suit the orebody. In this case, the concentrator changed from continuous operation to 11 day campaigns every 14 days. As is common in this industry, much of the unprofitable ore had been scheduled to "keep the concentrator full", in the mistaken belief that they would need to deal only with marginal costs given there was excess capacity.

This new approach had a significant impact on business performance. Concentrator performance became much more stable and the previously complex process control regime was much simplified. This provided a platform for further continuous improvement. Because plant operation was much steadier, the influence of different ore types could be easily seen, allowing the metallurgists to provide enhanced information for mine planning and ore scheduling.

The MIM lead zinc business had struggled for many years, despite excellent technology and a successful enterprise bargaining arrangement. Reducing variation in inputs with an integrated mine to mill approach was the critical factor that was necessary to get full benefit from these existing advantages. When the period of 1995/96 is compared with the period 1997/98, some of the results noted were:

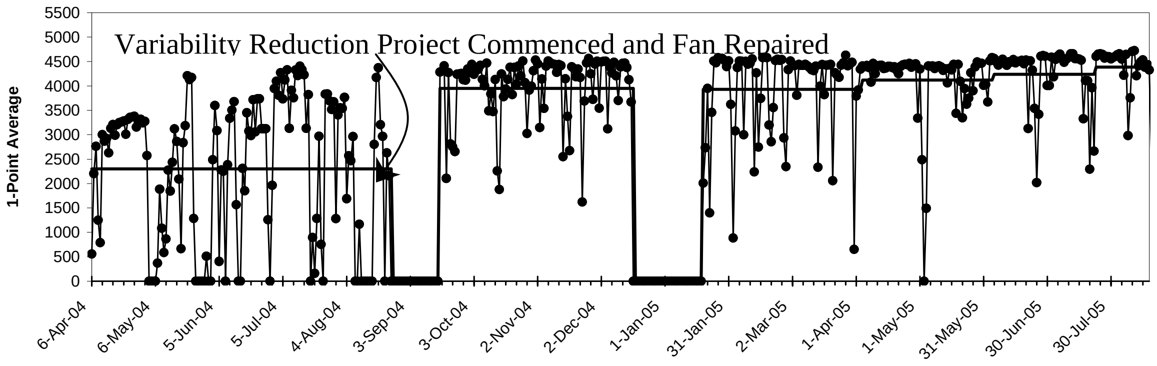
- MIM had a smaller, but more profitable and more robust business.
- Tonnes mined and treated dropped 35%, but so did costs.
- Lead bullion production increased by 10%, lead recovery increased by 5% and lead concentrate grade increased by 2%.
- Silver production increased by 6.5% and silver recovery increased by 5%.
- Zinc concentrate production dropped by 28% and zinc recovery increased by 2%.

OTHER CONTINUOUS OPERATIONS

Cement Plant

At Figure 3 is the daily tonnes output from a cement plant. The plant had a history of process related stoppages which limited production tonnes. At the same time that a variability reduction project was launched a major repair to a fan was undertaken. The combined effect of these initiatives can be seen in Figure 3. Not only did tonnes output rise immediately, but also quality improved and the reduced noise in the data made many other improvements possible. In the initial phase of the project the only two aspects to receive significant attention were reducing variation in inputs and reducing over-control and differences between shifts. Subsequent work both reduced stoppages and solved some quality issues. This plant ran for over a year without losing a whole day's production due to stoppages of any kind, and produced record tonnes that drove down unit costs.

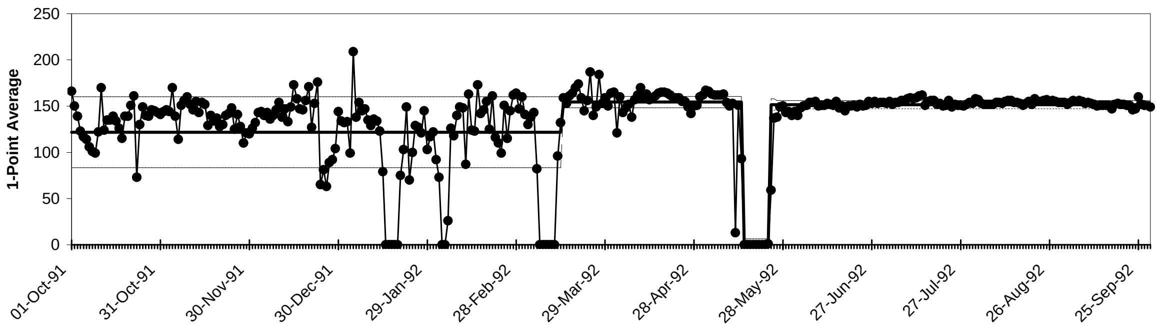
FIGURE 3
DAILY TONNES OUTPUT FROM A CEMENT PLANT



Vinyl Chloride Plant

Mr Robert Guttentag took over the Port Botany VCM plant despite its reputation for ruining careers. The corporate folklore joked that the plant was a graveyard for careers, and that no manager had ever been promoted out of the VCM plant. Nevertheless, Rob Guttentag accepted the challenge. At Figure 4 can be seen the fruits of his assignment to the plant. The major breakthrough was discovering that the single biggest cause of variation in the plant was over-control, both by operators and by the chemical engineers. When Rob Guttentag eliminated this over-control, tonnes output rose to record levels, unit costs fell dramatically and quality improved. He had demonstrated yet again that reducing variation improves quality, output capacity and profitability.

FIGURE 4
DAILY TONNES OUTPUT – VCM PLANT



CONCLUSION

These case studies illustrate the significant advances possible if a business focuses successfully on understanding and reducing variation, especially when the variation of inputs and to the early stages of the process is addressed. These lessons apply everywhere, but have been especially impactful in continuous processes such as mining and metallurgy, cement plants, petrochemicals and plastics operations and in high speed processing.

Improved quality, reduced scrap and rework, lower work in progress and inventories, higher throughput volume, lower unit costs and enhanced customer service levels. We can have it all, if only we know how to reduce variability.

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3. *Wysowl Pty Ltd,* MIM Site Investigation Report, 14th November 1996.