COM 2014 KEYNOTE: Process Control Applications in Mining & Metallurgical Plants Symposium

Manual Control, Process Automation – or Operational Performance Excellence? What is the Difference?

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* XPS (www.xps.ca) is an autonomous, consulting and testwork business providing specialist technical services to the global mining and minerals industry through five key discipline areas: 1) Process Mineralogy; 2) Extractive Metallurgy; 3) Process Control; 4) Materials Technology and 5) Plant Support. Contact XPS through: info@xps.ca

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ABSTRACT

The mining industry uses many types of mineral and metallurgical plants to produce saleable product from ore mined. Plant design history has left current operations with a mixture of manual operation and various forms of automated process controls. Consequently, we typically see high variability in the continuous operations together with a shortfall in the attainment of full capacity, or higher utilisation of consumables.

At a level of best practice, ‘Operational Performance Excellence’ focuses on process control, using automation and control systems to deliver process optimisation. This more sophisticated delivery is a great deal more difficult than the first stage of equipment selection / installation. It includes the appropriate selection of the right instrumentation, control system, key process knowledge, individuals with a solid control engineering background / experience, and the essential backing / support of the operations management team together leading to higher value delivery. Robust solutions can be realised, considerably minimising process variation, thus leading to process optimisation. This approach results in an easier, efficient and safer process while providing considerable returns for the plant owners.

How variable are your processes, and do you maintain optimised process performance with dedicated resources, modern instrumentation, ‘best practice’ control systems and performance monitoring tools? In this paper, these questions and their possible answers are discussed.
I say we can do MUCH MORE and be ‘more efficient’ in our efforts to remain competitive. This area remains a major opportunity for improved efficiency, minimising tailings losses and other milling costs.

KEYWORDS


INTRODUCTION

In introducing this topic, I remind you of these (global) historical comments to consider during my keynote, as these ’key champions’ are referenced in my talk, paper:

• Konigsmann (1992), “Process control is now an essential part of any (Canadian) concentrator operation. It provides a proven vehicle for improving operation economics by increasing revenues and reducing costs.” ... “The question one must ask is whether we are tapping the full potential of this technology? The answer: is ‘No!’ ” [MITEC Mineral Processing Technical Advisory Committee (TAC), acknowledged 2 problem areas: 1) small plant & 2) those plants who use some control but not achieving maximum benefit.]
• McKee (1997), ‘Process control is a broad term which often means different things to different people.’ Process control is: ‘the technology required to obtain information in real time on process behaviour and then use that information to manipulate process variables with the objective of improving the (metallurgical) performance of the plant.’
• McKee (1997), ‘There is a need to determine, and if necessary correct, the condition of the plant as a pre-requisite to control development. ‘Correcting plant limitations should be seen as a first step in the approach.’
• Blevins et al (2003), “Proper controller tuning is the largest, quickest, and least expensive improvement one can make in the basic control system to decrease process variability.”
• Fiske (2005), “ARC (Advisory Group) believes that those companies which are able to methodically implement, use, and maintain APC (Advanced Process Control) applications, at the lowest cost and generate the highest value, over its lifecycle will have a distinct competitive advantage.”
• Lynch, (2012), “Control is not a high priority here (Australia) even though the effect of inadequate control on the loss of mineral tailings is obvious.”

As such, the opportunities for you all to consider in the operating plants which you work in, or may have some responsibility for, are as follows:

• Is your feed stable?
• Are your instruments calibrated and performing?
• Are you aware of wireless instruments (including vibration)?
• Is your control system up to date and stable?
• Are you in manual or auto control?
• Are your Operators acting on alarms or are they nuisance?
• Do you understand and accept your process variability?
• Are you operating within the design targets and process constraints? ○ (pumps, cyclones, supplies, thickeners, roasters, furnaces, etc. etc.)
• Are you using your surge capacity, …. or running tight level control?
• Are you at optimum and are the controls robust?
• Are you benefiting from asset management systems?
• Are failure / fault detection systems implemented?
• Can you make the same product for less energy, or material consumption?
Do you operate with or without a Control Engineer?

Does your Plant / Process or Processes run as well as your car?

And, how do you accept your new Plant, or newly expanded process?

Each of these points should be carefully considered, as I believe – based upon the Process Control Group experiences observed from XPS, external clients, Glencore, Xstrata, Noranda, Falconbridge and Texasgulf, that we can do ‘Much More’ and be ‘Much More Efficient’ using the technologies, systems and expertise which we have available to us. Let’s look more closely at the broad topic of process automation and control engineering.

PROCESS AUTOMATION AND CONTROL ENGINEERING

Process Automation is understood, in a wider sense, to include / cover the following:

- measurement and instrumentation;
- process modelling and simulation;
- process monitoring and data reconciliation;
- data mining and multivariate statistics;
- fault diagnosis and fault tolerant control;
- process control, monitoring of product quality & control performance;
- off-line and on-line process optimisation;
- AI (Artificial Intelligence) methods: expert systems, neural networks, fuzzy control;
- Sequencing and automation.

This is a very large, fascinating field, with major opportunities in mining, mineral processing and ideal for Control Engineers! It goes far beyond what Plant Metallurgists and Instrumentation support personnel can (typically) handle and often requires many specialised training courses (e.g. the ABB / DeltaV / Invensys etc. control system, PROFIBUS, OPC etc.) on top of control engineering theory. Undergraduate courses very rarely teach the basics let alone have any ‘hands on’ courses/labs to illustrate control theory, or instrumentation practises, and the consequences of different tuning parameters, or control philosophies.

Before talking about process control, I would like to introduce you to Figure 1 and a key comment by McKee (1997), in his very important introduction to the AMIRA P9L project: The Optimisation of Mineral Processes by Modelling and Simulation 1996 to 1999. ‘There is a need to determine, and if necessary correct, the condition of the plant as a pre-requisite to control development. A good example is the importance of classifier operation and its effect on comminution circuit performance. Techniques exist (plant sampling, modelling and simulation) to audit the actual plant operation. Correcting plant limitations should be seen as a first step in the approach.’

Indeed, as we often see high variability in cyclone feed pressure, or when part of a circuit is shutdown, for example 1 ball mill in a 1 SAG x 2 ball mill grinding circuit. In my own experience I relate back to the copper cementation and cobalt removal process of the (former) Kidd Zinc Plant and our work in the early 1990’s to improve cobalt purification and reduce zinc dust (the key precipitation reagent). Under K. Kangas, as the Project Metallurgist, a cyclone recirculation system was tested, engineered and introduced after the first (of three) cobalt purification tanks. Accurate loss-in-weight (Brabender / Control & Metering) zinc dust metering systems were introduced; as was a (Massbal – now Honeywell) mass balancing control model, and an Advanced Control Supervisory program (developed in-house) - to accurately control the zinc dust feed rate setpoints to all 3 purification tanks. The consequences of the process change – introducing the cyclone recycling, was huge but together with the modelling, instrumentation, control improvements, far greater and in total 4.4 tpd of zinc dust was saved, resulting in...
an additional sale of $1.8 m per year in (zinc product) sales! The exciting hidden benefit though, was a substantial increase in online (processing) time from 88 to 95% percent – itself worth a considerable sum!

Process Control Will Not Correct Inherent Design / Flowsheet Problems (D. McKee, AMIRA P9L)

‘There is a need to determine, and if necessary correct, the condition of the plant as a pre-requisite to control development. A good example is the importance of classifier operation and its effect on comminution circuit performance.’

‘Techniques exist (plant sampling, modelling and simulation) to audit the actual plant operation.’

‘Correcting plant limitations should be seen as a first step in the approach.’

e.g. Co Purification: 4.4 tpd saving @ $1.8m/yr value & 88->95% online time!

Figure 1 also shows (Fragomeni et al 2006) mineralogical assessment equipment which XPS has (in the Centre at Falconbridge) for completely analysing existing plant stream samples, or drill core samples (off-line), as well as MPP (mini pilot plant) equipment to diagnose and confirm milling processes and complete flotation circuits. With correct sampling and statistics, surveys, results are obtained at a 95% confidence level. These tools are essential in checking and correcting plant performance, or new plant design, ensuring minimal wastage of precious paying mineral resources, to tailings or ensuring best possible concentrate grades for upstream processing at lowest treatment penalties.

Figure 2 illustrates a milling operation which introduces a sump discharge into a cyclone overflow stream and shows the effect on cyclone overflow density (COFD). Note, COFD is the product from grinding – to the customer – flotation. Flotation always wants a consistent particle size, feed flow and feed density; together with the liberated pay mineral. As the sump kicks on, it dramatically disturbs the COFD. When off, there is good control around the target setpoint. Clearly this is not a control problem, but a process problem. It has run for many years, too many years, and the consequences of the ongoing disturbance are not that visible to the Operators. It certainly would be more visible if there was an online particle size measurement on the cyclone overflow! Collection, (of the sump – originating from a dust collection system in the crusher plant) into a holding tank, with a smaller, more controlled bleed into the process stream is a better process solution – but easier said than done. Alternatively a smaller – more continuous flow, from the sump is one which would be better for the process, but this requires addition of extra water – unnecessarily diluting pulp density. Once the plant is operational, it can become very difficult to resolve simple, yet highly disturbing process issues, such as this one.
Figure 2 – Cyclone Overflow Density (COFD) With and Without Sump Pumping

Figure 3 illustrates the Process Control Group’s classic symbol, as we have championed process control, for at least three decades now. Thwaites (2007), “the figure is a general diagram to illustrate the overall process control objective for any key variable: feed, density, flows, pressures, temperatures etc. Measure and understand the initial variability, stabilise and then optimise to the constraint of the process. As a Control Engineer, we need to understand i) the metallurgical constraints of the process; and ii) the equipment constraints. Typically throughput benefits will come from an increase in the setpoint, and consumable savings will come from a decrease in the setpoint. Once these have been achieved it is important to ‘maintain the gain’ by ensuring the changes are robust, thus benefiting the plant.” Classic examples which the audience can relate to are ‘cruise (speed) control’ in vehicles and temperature control in houses and rooms. Note other logos which we have seen may only show the variability reduction (with control) and not the optimisation step – often requiring advanced process control (APC). Variability reduction is a recommended pre-cursor to optimisation. It may have a small value and be an easier to operate, safer process, however the true value to the business (and Plant Manager) is the ability to push to the constraint and robustly hold the process at a different operating point. The value of this, when it can be consistently sustained, is huge and often very significant to the operation.

Figure 4 illustrates poor (no control) to optimised control as distributions, common to Six Sigma and Statistical Process Control. Note in the second step, under control, the Figure shows a tighter distribution and in the third step, ‘optimise’ the process mean has been shifted providing a key measurement to quantify the result. Holding the process at a particular constraint can take as much (development) work as was taken to reduce the process variability. Note an offset (in the mean) may also arise from poor tuning parameter selection, for example flotation level control ‘Integral’ parameter in the level PID control, as also shown in Figure 4’s plot of ‘bias elimination.’ Reducing the variability requires a good foundation and knowledge of control engineering and instrumentation. Filtering, retuning may be the solution, but also other control and instrumentation solutions may be required.
Process Control – XPS
As we have practiced, championed for over 3 decades!

Figure 3 – Process Control – XPS: Measure, Control, Optimise

Poor to Optimized Control

1. Measure
2. Control
3. Optimize

Figure 4 – Poor to Optimised Control

The process control objectives, leading to operational performance excellence, can therefore be simply summarised as the Management of TOOLS & RESOURCES to consistently:

- Minimise Process Variation;
- Optimise Process Performance;
- Minimise (Fixed and Variable) Costs;
- Control Product Quality;
- Maximise Safety.

Figure 5 illustrates the classical layering of Process Control (*Thwaites (2007), Jones (1994, 1996)*). Like Figure 3, we have referenced this key diagram for over three decades, as we have championed process control throughout Falconbridge, Noranda, Xstrata and now Glencore. *Jones, Morrell (1996)*, discuss a figure showing levels of control (as used by one of the authors in a 1969 article), whereby Level 0 represents the Process I/O (Input/Output), Level 1 the Regulatory Level, Level 2 Supervisory Control, Level 3 Unit Optimising Control etc. As shown in Figure 5, we show the processes at the bottom level, followed by the Instrumentation Inputs/Outputs, i.e. measurements. Without any control, this then is shown as Manual Control. Loop control, the ‘Regulatory Level’ is on the next level and can be done both in the field, or in a central location, by panel based controllers (typically single loop), or DCS (Distributed Control Systems), or PLC (Programmable Logic Controllers). Note PLCs, in their history, were never designed to operate plant wide control supporting many PID control loops. Advanced Process Control (APC) is layered above the regulatory control operating on the regulatory control loop setpoints. Above the Process Optimising Control, is the Plant Optimisation. As we move up the triangle the complexity increases, but also, so does the economic returns. Any problems in the lower levels, or functions, will of course often prevent the optimisation. Furthermore expecting any advanced control to be successful when the regulatory control has not been closed, or tuned is naïve and unrealistic, especially in mineral processing plants.

**Layering of Process Control**

**General Process Control Hierarchy**

![Layering of Process Control Diagram](image)

Figure 5 – Layering of Process Control

While process and area optimisation can have considerable financial returns, it is well recognised (and reported), by those practising process control, that this can only be achieved by having a robust and solid regulatory lower level.
(McKee, 1999). “Svedala (metso minerals) advocate a systematic approach to process control:

- start by defining what is important through an analysis of the process (an audit) to determine what is required and the level of control;
- understand the process and ensure the basics for good control are in place (e.g. instrumentation);
- match the installed system to the capability of the people available;
- recognise the on-going commitment required for success;
- with regard to the actual control, consider three levels as follows:
  - basic PID - via DCS or equivalent;
  - supervisory (cascade control, dead-time compensation, etc. - via DCS or equivalent);
  - optimising (e.g. expert system, adaptive) - via a package such as Gensym’s G2 or implemented within the DCS.”

Figure 6 (Ruel 2012) is a nice illustration showing that most plants have the bulk of their control investment in the basic regulatory DCS. Additional, (approx. +33%) investment is required for ‘Coordinated Control’ and ‘Advanced Automation’ – not nearly so common. However, in terms of ROI, ‘Coordinated Control’, ‘Advanced Automation’, and ‘Optimisation’ have a much, much bigger return on investment (ROI) – directly impacting business profitability. Exactly what the Plant Management wants to know, hear, and report up.

So what are the Control Technology options available to us to control our mineral processing processes and plants? Of course it starts with ‘Manual Control’ where we need manpower to adjust valves etc. in order to adjust flow rates (like water, chemicals, flotation air flow etc.). The bigger the plant, the higher the throughput then the number of manual valves, feed rate controls etc. increase. A couple of important points, are 1) our Operators, in such a plant, will know valve positions (2 turns open etc.) and not necessarily the engineering unit of flow rate, like meters/min of water flow, cc/min of chemical etc.; 2) each Operator will have their own way of operating – readjusting from shift to shift. It is far better to have
our Operators work in engineering units and set the setpoints of the control loops, and let the controller adjust the control valve – typically on a 1 sec. basis, in order to keep the flows at the targeted setpoint. These ‘regulatory’ loops then only require a periodic update of the setpoint, and can vastly reduce the Operator input, saving valuable manpower costs – keeping the process at an acceptable operating point. Regulatory control is predominantly done by PI, PID control loops operating in the control system – the DCS (or in some cases the PLC). PI and PID control can often be (but is rarely) enhanced, for negligible cost, by adding a feedforward signal / term allowing the controller the ability to make a final element valve change when a (measured) disturbance comes to the process. Final adjustments are done by the feedback control on the error between the measurement and the setpoint. It is important to point out that PI and PID control cannot predict where the process is going in the future and if it is going to violate a constraint. However this is possible, for the few loops which require it, with MPC – Multivariable, Model Predictive Control (Boudreau and McMillan 2007; Jonas 2008; Yutronic and Toro 2012). Mineral processing plants could benefit with more MPC controllers.

PI and PID controllers can easily be enhanced further by configuring them as cascade or ratio controllers, for example water feed, ratioed to tonnage feed, and flotation chemical additions ratioed to flotation feed metal units.

Many of our flotation cells operate with dual dart valves, and as such, require a ‘Split Range’ controller. These are rarely setup properly – in new plants, and often are not operating to their full potential, requiring constant Operator intervention or poor performance of the flotation cell (through cell level being outside the process constraint), as illustrated in Figure 25.

Fiske (2005) “The primary role of regulatory control is to ensure stable, safe, and reliable operations while maintaining process units at a desired or specified condition” – reducing variability. “It does not attempt to continuously improve operations in an economically optimal manner.”

A summary of our control options, are as follows:

- Manual Control … usually acting on valve position (i.e. % opening, or motor drive speed);
- PID Control … process variable (PV) & setpoints (SP) in eng. units – i.e. automatic regulatory control based upon the PID control algorithm:
  - Feedback only (SISO …. Single input, single output);
  - Feedforward and Feedback (MIMO, Multiple input, multiple output);
  - Ratio Control and Cascade Control;
  - Split Range Control;
  - Smith Predictor….. dealing with significant time delay.
- MPC (Multivariable Predictive Control) or Model Based Control … based on true process dynamics, and using recent history & a model based trajectory ;
- Rule or Fuzzy Control … based on human knowledge / experience;
- Automation Control of:
  - specific known actions or sequences; batch processes; etc.
- Advanced (Optimising) Process Control.

More detailed descriptions of control technology options can be found in the references: Ruel (2006, 2014); Boudreau and McMillan (2007); Hodouin (2011); and Flintoff and Mular (1992).

Let’s take a closer look at the standard (PI and PID) controller. Figure 7 shows two basic controllers, the first used for room temperature control (cruise ship) and the second for dual zone vehicle inside temperature control (1997 vintage). For the former a value is not shown, neither is any indication where the output is (i.e. 50%). Also the setpoint value is not shown and the controller indicates the comfortable target setpoint, allowing the freedom to move this either up or down, improving comfort. Simple and effective automatic control, but not allowing: 1) manual control, or 2) any automatic
optimization of the temperature during the day. The latter is a dual loop controller in ‘Auto’ with manual control switching and allowing a different target setpoint. Again, basic control loops allowing the (driver and passenger) to manually adjust their setpoints.

Figure 7 – Simplest of Controllers … we all know!

Modern Data Acquisition & Control System
(Emerson DeltaV DCS – Distributed Control System):

Consisting of:
- Flexible I/O structure
- 10/100 MBaud Ethernet
- PC technology
- Integrated Historians
- Plant LAN connectivity using OPC
- Easy to use Software Integrating it all Together

Figure 8 – Modern Data Acquisition and Control System – Emerson DeltaV DCS

In our mineral processing plants we (usually) have more complex control systems, as shown simplistically in Figure 8, as often there are several hundred regulatory control loops, as a minimum, together with different instrument Input/Output (I/O) networks etc. Instrumentation can be on (classic) 4-20 mA networks, H1 (Foundation Fieldbus), DeviceNet, Profibus networks etc. The latter (most buses)
provide both the process measurements as well as other key digital information of the device on the network. Furthermore, individual wiring of the devices is not necessary, reducing installation costs. Above the controllers, and I/O modules, you will see the Operator workstations, as well as a (OSIsoft’s PI) plant historian database, accessible from the Plant LAN (local area network).

Figure 9 illustrates flotation cells in one of our Mineral Processing plants. Prior to upgrading, there was one air supply for two flotation cells under manual control. Cell performance was therefore impacted by air supply changes, blockages and varying, uneven pulp levels, thus requiring constant Operator attention. Note Operators would ‘know’ key valve positions (turns) but not individual air flow rates. After upgrading, individual air flow control was provided to each flotation cell with the measurement and control in engineering units, as these became classic regulatory PI, PID control loops.

Now let us take a look at one of our ‘typical’ controllers in the Mineral Processing plant, under automatic, regulatory control, while noting that for all tuning the importance of good measurements and final control element design goes without question. Figure 10 illustrates further work to improve tuning of the air flow control loop. The process remained the same, as did the air flow measurement and control valve. Shown is the difference in controller tuning parameters. They are significant and very import as one moves from regulatory control to optimised control. Before the changes, a change in air setpoint would take approx. 15 mins. (to return to the new setpoint) and really this is no issue if they are only changed once, or twice a shift. As under regulatory control, this is far better than a manual valve being periodically adjusted by an Operator. However, if air flow setpoints are to be optimised – as they should be, or could be (under metallurgical control), then retuning can result in a much faster, more responsive loop – stabilising almost immediately, as required by a froth velocity control loop, cascading new air flow setpoints on a 1 minute control interval, for example. As you might appreciate, the consequence to the next level of control is huge, not to mention allowing a completely different upper loop control interval, and one more appropriate to the dynamics of the flotation process.
Note, flotation air systems are often complicated by fan and air duct designs ahead of the flotation cells. Multiple PID loops to the different cells on the duct work very often fight each other, and the engineering design does not always take into account that the duty for a rougher is different than a scavenger. Challenges with flotation control requires the process design covers controllability in the operating envelope that handles the variability from changing head grades and feed tonnages – whether automatically or manually controlled.

Systematically taking this (retuning) approach through the flotation circuit takes one to the cleaner circuit, where column flotation may be used for cleaner cell upgrading. Figure 11 illustrates a feed variability reduction of some 56% which was then correlated to concentrate grade variability reduction: some 79% reduction in the Ni (impurity) in the Copper Concentrate grade (Jin et al, 2013). These kind of improvements have an overall benefit on the Mill’s performance, impacting the bottom line and pleasing the Operation’s Manager.

Figure 12 (Bouchard et al 2010; Émond, Vynogradova, 2010) illustrates similar results on a grinding circuit in our Platinum processing plant in South Africa. Through control improvements on Mill Feed, reducing variability by 72% (i.e. standard deviation of 50 to 14 tph); and better flotation feed density control (56% reduction in variability) utilising an installed density meter rather than a steady state water addition model etc., primary grind improvements were measured to improve from a decrease in grind size from 42% to 52% minus 75 micron (improving mineral liberation) and an increase in primary rougher recovery from 60 to 73%. Overall plant recovery was increased by 3% and final product grade by 10 g/t on a feed grade of 2.5 g/t PGE (platinum grade elements). These are very significant results coming from the variability reduction efforts and subsequent control improvements using the same processing equipment.
Column Flotation - Feed Control

Objective:
1. More flexibility
2. Increased feed stability

Feed Variability Reduction: 58%

Feed variability reduction (of 58%) then correlated to concentrate grade variability reduction:
- 79% (std. dev.) reduction for the column Ni (impurity) in Cu concentrate grade

Figure 11 – Column Flotation – Feed Control … Regulatory Control

Eland Mill (2010) Overall Recovery Improvement from:
Primary Grind & Primary Rougher Recovery Improvements

On a feed grade of 2.54 g/t PGE:
- Sec. rougher tails dropped 0.24 g/t;
- Overall plant rec. increased 3%;
- Final concentrate grade increased by 10 g/t.

Figure 12 – Eland Mill (2010) Overall Recovery Improvements from Primary Grind & Primary Rougher Improvements
Emerson (2007) have stated (in their DeltaV embedded advanced control presentation) that, as an industry average 75% of assets are under process control, but over 60% of all control loops are under performing, and this poor performance results in:

- High product quality variability;
- Reduced throughput;
- Increased downtime, lower availability; and
- Poor financial performance.

For the “Mining Industry” poor loop performance is often due to:

- Poor tuning knowledge / practise;
- Feed variability changing the tuning parameters – or a lack of ‘gain scheduling’;
- Measurement problems (i.e. scale on pH probes, flotation level measurement floats sticking or cracked floats etc.);
- Problems with final control elements / actuators;
- Poorly designed control loops – not identified in design or commissioning.

Where are you at in your Plants, or newly commissioned processes? Yes regardless of initial and green field, or brown field investment, your new plant may in fact be worse than this (60% of your control loops underperforming), if commissioning was not completed properly, if there are measurement / final control element problems, if regulatory control loops were incorrectly configured, poorly designed and (mostly) not tuned properly or optimally, following commissioning. Additionally, feed variability may require different tuning parameters for acceptable performance.

Control System Commissioning Status
after 6 months of Plant commissioning (June 2013)

New, processes / plants / projects

“Commissioning of the PCS & PLC systems will not (should not) be considered to be complete unless:

a) all systems are connected, trouble & error free;
b) all designed and configured regulatory loops have been acceptably tuned and are operational in automatic;
c) as well as specified start-up and shutdown sequences configured / tested; &
d) alarm / group alarming implemented.

This then will allow effective, safe, centralized control.”

XPS Process Control Group

Last new project, what we saw was:

Control System Status after 6 months:

- Commissioned status (DCS) = 94%
- Regulatory loops on Manual = 37%
- Regulatory loops on Auto = 63%
- 16 % (of Man. Status) have field instrumentation or logic issues
- OSIsoft PI – just introduced

Figure 13 – Control System Commissioning Status after 6 Months – New Plant

The XPS Process Control Group recommends (Figure 13) for new plant, processes:

“Commissioning of the PCS & PLC systems will not (should not) be considered to be complete unless:
1. all systems are connected, trouble & error free;
2. all designed and configured regulatory loops have been acceptably tuned and are operational in automatic;
3. as well as specified start-up and shutdown sequences configured / tested; and documented; and
4. alarm / group alarming implemented.

This then will allow effective, safe, centralised control.” It is also a pre-cursor for optimisation and advanced control.

A site visit six months after commissioning – Figure 13, on one of our very well designed and constructed new mineral processing plants, soon running at, exceeding, design of 70 ktpd, we observed the following of the installed Control System Status:

- Commissioned status (DCS) = 94%;
- Regulatory loops on Manual = 37%;
- Regulatory loops on Auto = 63%;
- 16 % (of Man. Status) have field instrumentation or logic issues;
- OSIsoft PI, as PMIS historian – just introduced, and not available for start-up, commissioning.

The plant design had approx. 145 regulatory control loops. Advanced control, was soon after implemented on SAG mill feed and has been observed to be very beneficial (as compared to manual control) with impressive initial results, however the installation proceeded in the absence of building on a strong, well tuned regulatory layer, a necessary building block and fallback position.

**Control Tuning Summary**

*Don’t underestimate the impact!*

"**Proper controller tuning is the largest, quickest, and least expensive improvement one can make in the basic control system to decrease process variability.**"


N.B. Book was inspired by DeltaV Advanced Control Products. Available from ISA or may be ordered at EasyDeltaV.com/Bookstore
Thornton, Prinsloo, Tewu (2009) “The authors have found in practice that one of the fundamental barriers to effective SAG mill control is simply poor tuning of feedback control loops.”

Please now think how you accept a new automobile, and the state of the engine controls etc.! All sensors, controls have been tested, are fully functional, and the ‘check engine’ light will not be activated.

As Blevins et al (2003) stated: “Proper controller tuning is the largest, quickest, and least expensive improvement one can make in the basic control system to decrease process variability.” Further discussion can be found in the book “Advanced Control Unleashed” available from ISA or EasyDeltaV.com/Bookstore. The book was inspired by DeltaV Advanced Control Products, Figure 14. Also note the course manual “Fundamentals of Process Control” (Ruel 2006), from Top Control, now BBA.

AUTOMATION AND ADVANCED CONTROL

Dictionary.com states Automation as:

1. the technique, method or system of operating or controlling a process by highly automatic means, reducing human intervention to a minimum;
2. a mechanical device, operated electronically, that functions automatically, without continuous input from an operator;
3. act or process of automating;
4. the state of being automated.

Note, automation is not process control in itself, however process control may use, and should use, automation. So where do we see it and how do we apply it? I present both simple and more complexed examples.

A very simple example, as introduction which you can all relate to - is a washing machine and a dish washer. The tedious task of washing has been automated to allow time to be better spent doing other activities. There is no need for me to explain further these well known examples.

Automation can be done on various platforms (PLC or DCS), on specific process units or areas of the Plant. While I am not aware of a fully automated Mineral Processing plant, I have fairly recently visited an ‘Unmanned (Hydro) generation station (water turbine / generator)’ – at Sandy Falls (Timmins), where the (power generation) process is relatively simple. Recently, PYROGENESIS (Holcroft and Carabin 2012) reported on their ‘Plasma Arc Waste Destruction System’ for the US Navy Carrier, Marine vessels & mobile units – a fully automated process, required to be ‘idiot proof’ for the Operator.

Some Automation examples which we commonly see in the minerals industry are:

• Motor starts and stops e.g. crushing plants; and sump pump controls;
• Remote starts, start-up and shutdown sequences, which can be quite complex;
• Mill lube systems;
• Conveyor belt material handling systems;
• Mine Drilling equipment and (Mine) Autonomous haulage:
  • “Vale puts Railveyor to test” – Sudbury Mining Solutions Journal, Sept. 2012;
  • “A key pillar of Rio’s mine automation initiative is autonomous (vehicle) haulage” - Technology Case Study: Rio Tinto, Mining, People & the Environment, Jan. 2012;
• Pressure filtration & Batch processes;
• Automated metal (plate) stripping, as we use for Ni, Cu & Zn stripping;
• etc. etc.
Figure 15 illustrates a particular area of specialty for Glencore and XT – automated copper stripping machines.

Prior to 2002, the stripping of refined copper cathode from stainless blanks was accomplished through the use of custom electro hydraulic machinery. Very successful, but the systems were quite complex.

The first two (robotic) systems were installed at the LS Nikko Copper refinery in Ulsan South Korea in 2005/2006.
The next system was installed at the Jinlong refinery in Tongling China in 2008, with subsequent further installations at other facilities in China.

Figure 15 – Automation – First Installations – Robotic Cathode Stripping Machine

Prior to 2002, the stripping of refined copper cathode from stainless blanks was accomplished through the use of custom electro hydraulic machinery. Laezza, Box, Scott (1990) “The Kidd Creek Copper Refinery, one of the most automated and mechanized refineries in the world, has been in operation since 1981.” “With the invention of the KIDD PROCESS stainless steel cathode blank (Canadian Patent # 1263627) it became necessary to design and build a material handling system which included an automatic stripping system. Advantage was taken of the opportunity to include special design features providing for a more efficient cathode washing system, cleaning of the hanger bar contact-surface and better packaging of the end product.” Yes a great example of automation in our industry.

The process was extremely successful, but the systems were quite complex, fairly maintenance intensive and were challenged to recover quickly when off-spec product entered the system. “In some cases this resulted in less than acceptable machine up-time & it was determined (in 2003) that the bulk of the system downtime occurred, not during the actual product processing, but during product handling.”

In 2003 the system was completely redesigned by Ionic Engineering (Sudbury, Ontario, Canada) in cooperation with Xstrata Technology (the Group responsible for the Falconbridge Kidd Process). The new design featured the world’s first use of high capacity, high reliability industrial robotics – Fanuc Robotics - in a copper refinery application. The first two systems were installed at the LS Nikko Copper refinery in Ulsan South Korea in 2005/2006. The next system was installed at the Jinlong refinery in Tongling China in 2008, with subsequent further installations at other facilities in China. Some key metrics, in the technology improvements (by using robotics) that were implemented are:

- Machine Uptime – In excess of 95%, far better than all prior designs;
- Power Consumption – Over 50% Reduction, and 390 kW down to 175 kW;
- Number of Sensors – 48% Reduction, 140 down from 270;
- Number of Actuators – 53% Reduction – 22 down from 47.
In time, we will see much more robotic applications, and I believe far more automated sequences in our control systems, however presently this is a key area where much more development and novel applications are required. Don’t forget an automated sequence is one which is driven the same way, every time and not one open to Operator interpretation – each Operator’s interpretation. An automated sequence is also one which will highlight any problem or failure in the system completing the sequence.

Let’s move onto Advanced Process Control (APC), and here I share quotes by Fiske (2005), before presenting a couple of examples: “In terms of automation functionality, regulatory control & APC serve much different purposes.” “The primary role of regulatory control is to ensure stable, safe, and reliable operations while maintaining process units at a desired or specified condition” – reducing variability. “It does not attempt to continuously improve operations in an economically optimal manner.” “APC, on the other hand, is a supervisory control application that coordinates a large number of parameters to maintain control closer to operating constraints and more favourable economic operating conditions.”

Figure 16 “ARC (Advisory Group) believes that those companies which are able to methodically implement, use, and maintain APC applications, at the lowest cost and generate the highest value, over its lifecycle will have a distinct competitive advantage.”

Figure 16 – Advanced Process Control (APC) – ARC Insights; XPS Process Control: Measure, Control, Optimise

Thwaites (1993). Figure 17. “Up until the mid 1980’s Supervisory Process Control had only been applied in one of the Kidd Creek Metallurgical Plants - the Concentrator. The on-stream analysis system and central control design were key to the development of a supervisory reagent system running on economic efficiencies calculated from smelter contracts. Optimum metallurgy and 25% lower reagent costs were the direct economic benefits from this development effort. In 1986 a decision was taken by Kidd Management to apply Supervisory Process Control throughout other areas of the Metallurgical Site. The Kidd Creek Zinc Plant was given a priority to apply Supervisory Process Control at this time.” The example presented – Figure 17 was selected to illustrate the considerable economic potential that was realised with the application of (then) current computer and software technology to the Supervisory Process Control of Kidd Creek Metallurgical processes in the Zinc Plant. “On-line steady state modelling, dynamic modelling and multi variable predictive control, and conventional programming have all been applied to improve the competitiveness of the Kidd Creek Zinc Plant.”
Advanced Process Control (APC)

Hydro Management & Site Peak Power Control

"Economic Benefits of Supervisory Process Control at Kidd Creek"

Hydro Management & Site Peak Control Objectives:

• Improve knowledge & awareness of power costs
• Improve & stabilize SITE power control (at approx. 133 MW of power consumption)
• Control the ‘daily’ Peak load and shift power consumption to ‘Off Peak’ while maintaining production
  - Using 3 zinc plating rectifiers at approx. 22 MW maximum power each

Results:

1. Lowest overall (c/kWh) Ontario Hydro Mining customer using TOU (time of use) Hydro rates

2. Cumulative (5 year) total savings from 1989 to 1993 incl. = $17,600,000

   1. 1989 = $2.0M saving on 1,089,851 MWh
   2. 1990 = $2.4M
   3. 1991 = $3.5M
   4. 1992 = $5.6M
   5. 1993 = $4.1M saving on 1,076,755 MWh

Conclusions:

• There are MANY more OPPORTUNITIES throughout the Metallurgical processes for supervisory control
  “APC, can have considerable returns .... to help the Business!”

In 1989, Ontario Hydro introduced time of use (TOU) power demand and energy consumption rates in their monthly billing, for both winter and summer (6 months each) months and defined on/off peak periods. Following a close scrutiny of the monthly billing, and installing key metering equipment, we were able to monitor the entire Kidd Metallurgical site’s power demand (approx. 133 MW) and consumption (approx. 1,089,851 MWh in 1989) on a 1 minute average time basis. Using the MODCOMP computer, the Technical Computing Group, under J. Carriere, soon was able to duplicate the entire bill for both the whole site and also each of the major Plants: Mill, Zinc Plant and Copper Plants. The (second by second) consumption data was also made available to a single loop (panel based) controller (there was no DCS) which controlled three panel based ratio controllers – each in control of a zinc electroplating circuit consuming, under maximum power some 22 MW. For the three circuits, 66 MW soon proved ample to control the Site’s 133 MW power demand and peak power demand on a 1 minute basis. The Supervisory control computer switched the site peak control on automatically for the start of each day shift, returning it to manual at the end of the day (11 pm) and each weekend and statutory holiday. Furthermore, at the start of these ‘off-peak’ periods, the Supervisory Computer would also ramp rectifier production up to maximum – thus allowing production to ‘catch up’ at cheaper ‘off-peak’ periods. Important to note is that at the end of the 24 hr period, and week, no Zinc production was sacrificed in the control of the site peak and the rectifiers (66 MW total) were the best load to ‘trim’ or ‘take advantage’ of any load changes in any of the Site’s processes – automatically on a 1 minute basis. A simple but very effective advanced control strategy – programmed in FORTRAN, with a simple Operator interface, using automation (for the automatic switching of the peak controller and the automatic ramping up of each zinc rectifier circuit for ‘off-peak’ periods). The setup also allowed the site to quickly (within 15 mins.) and dramatically, reduce power demand, for example to a contracted 89 MW (from approx. 133, 143 MW etc.), when Ontario Hydro (the utility) had supply problems. This ability further saved additional penalties on several occasions. The cumulative (5 year) total Hydro savings to Kidd (from 1989 to 1993) – as presented to Falconbridge President, F. Pickard, was $17,600,000, as compared to no control and the Ontario Province average mining rate. Clearly, Kidd being an integrated metallurgical site was best able to implement such an effective strategy – but this is rarely addressed in the design of new plant, let alone a fully integrated
site. To be effective, such a strategy requires a shed able load, and (importantly) over capacity, as well as real time pricing and consumption monitoring / control on a second by second basis plus the control technology. “APC can have considerable returns …. to help the Business.” Referring back to Figure 5, this example represents control at the very top of the triangle – optimised plant / site operation.

DeltaV (Emerson) – Systematic Approach

DeltaV APC blocks are “Drag-n-Drop” &

Embedded in controllers, not in a separate system

DeltaV Embedded Advanced Control

A Systematic Approach for Sustained Performance

Identify Problems
And Prioritize

Analyze and Diagnose

Ro Tune
Or Fix Cause

Monitor Performance

Advanced Control

Advanced Control:

● Fuzzy Logic
● Neural
● MPC (Model Predictive Control)
Predict / PredictPro

Other Control System Suppliers MUST follow Emerson's lead making Advanced Control more easily available / configurable in the Control Systems used by Mineral Processing Plants.

Figure 18 – DeltaV (Emerson, 2007) – Systematic Approach to Apply Advanced Process Control (APC) in the DCS

The teams at Kidd Creek (including Process Control and Technical Computing, supported by the Operations and Site Management) showed a consistent, systematic approach to improving process control and applying advanced process control. The approach was presented to Noranda (Thwaites 1993) at one of their technology conferences. Figure 18. DeltaV, by Emerson also (later) show a nice systematic approach in applying advanced process control from within their DCS (Distributed Control System). This is generally uncommon and yet a huge area of need in our Minerals industry. Even, to this day, the bulk of advanced control has been done with external systems (such as the MODCOMP supervisory computer systems at Kidd) or control packages – such as the Honeywell’s ‘ProfitSAG’ Figure 19, Gensym G2 (Suiches et al 1999) – as applied at Noranda’s Brunswick Mill and Invensys’ Connoisseur – the MPC package (originally written by Dr. D. Sandoz, and available to us since 1989) which we were more familiar with at Falconbridge.

Emerson’s DeltaV DCS (Figure 18) allows (if you purchase the license) advanced control using Fuzzy logic, Neural networks and MPC (model predictive control). What we like, is it is like an extension to the existing control blocks and can be utilised on small and large applications. For example a ‘model based’ flotation froth velocity controller could easily cascade setpoints down to (well tuned regulatory) flotation froth air flow (PID) controllers and flotation pulp level (PID controllers); then be duplicated for the larger flotation circuit. Importantly all the key control blocks are running in the control system architecture, where historically the DCS has not had the computation ability to perform MPC, e.g. Connoisseur and Invensys I/A DCS. Figure 19, at Collahuasi (Yutronic and Toro 2010) presented an MPC
application of Honeywell’s ProfitSAG as a better solution than Expert Systems (see also Jonas 2008), for the control of the three lines (SAG and Ball Mills) controlling approx. 140 kt per day.

Figure 19, Honeywell’s ProfitSAG is an MPC solution for SAG Mills and includes:

- Objective function designed to accomplish the goals (maximise fresh feed rate), by manipulating (fresh) feed rate, mill speed, and solids content;
- Fault tolerant policies (anti-windup integration with regulatory control level);
- Fully integrated with measured disturbances, such as returned pebbles and particle size.

The Collahuasi Solution: MPC ProfitSAG replaces Expert Systems (Rules)

Honeywell’s ProfitSAG is an MPC solution for SAG Mills
- Objective function designed to accomplish the goals (maximise fresh feed rate)
- Fault tolerant policies (anti-windup integration with regulatory control level)
- Fully integrated with measured disturbances

- Collahuasi, Chile 3 SAG lines at approx. 140,000 tpd

The Collahuasi operation has run many years on ‘Expert Systems’ and now prefers the MPC approach provided by the Honeywell ‘Profit’ controller. Incidentally, this is all on top of ABB regulatory control system (DCS) and regulatory controls. The current Collahuasi approach has come from much learning at the Codelco plants and Kairos (Zamora et al, 2010), in itself the result of the AMIRA P893 benchmarking study (Mujica et al 2005) – Review and Benchmark of Process Control and Automation (in South America). For this review Falconbridge allowed Collahuasi and Noranda allowed Antamina operations to participate in the benchmarking and comparison. It was an important and very rare benchmarking exercise looking into the level of process control and automation at key Concentrators operated by different mining companies. I will make another reference to an outcome of this interesting study later in the paper – under the area of asset and performance monitoring.

Jonas (2008) commented on MPC: “Use of MPC for mineral and mining industries offers improved benefits and more sustained benefits over the long term. This is achieved by the use of technology that delivers better control and more optimisation, while at the same time offers a system that is easier to use, modify and maintain. The sheer volume of applications in mining and other industries are a tribute to the success of this technology.”
Jonas (2008) goes on to say: “The mining and mineral processing industries can improve business results by adopting an automation strategy more aligned to the other industrial sectors. This can be achieved by embracing more mature and better advanced control solutions, and reducing expenditures in other technologies that deliver fewer benefits.”

Ruel (2014) describes how to make advanced control choices when difficult processes need improvement. He concludes, “Advanced control is powerful but should be used after an evaluation of needs and expected performance.”

ELEMENTS NECESSARY FOR SUCCESSFUL PROCESS CONTROL

Figure 20, ‘Elements Necessary for Successful Process Control in Metallurgical Plants’ have been discussed, presented in the past (Thwaites 2007) and are summarised again in this figure (Figure 20). They are very important and MUST include:

- Tools – Instruments; Systems; Technology etc.;
- People – Control Engineers / Process Knowledge, Instrumentation Technicians / Specialists;
- Actions – Support; Management; Company; Technology transfer;
- Successes – Results and examples for further leverage, application.

Figure 20 – Elements Necessary for Successful Process Control in Mineral Plants

Success demands a Team approach, and Operational Performance Excellence can rarely be achieved without these key elements, so please take note. Furthermore, solutions need to be robust and layered on good regulatory control. They also need to be discussed and presented.

INSTRUMENTATION – A COUPLE OF SOLUTIONS ‘TO BE AWARE OF’

I would like to have a short discussion on instrumentation, as if we cannot measure, or actuate, we cannot control! Instrumentation technology has progressed significantly over the last three and a half decades, and several examples can readily be discussed, from particle size analysis, stream chemical
analysis to pH innovations, basic level measurements and flowrate measurements. Time restricts me to what I can present but I will start with the difficult area of basic mobile equipment monitoring (Rana 2013).

### U/G Mining Mobile Equipment Monitoring – Ni Rim Mine

**OSisoft Users Conference 2014 (Petroski, Symboticware, Bose, Rana)**

**U/G Mobile Equipment Data Management at Sudbury Integrated Nickel Operations Nickel Rim South Mine**

By the middle of Q4 2012, Symbot units were installed and commissioned on the 6 LHDs. The figure shows the installation of a typical SYMBOT unit. The datasets are made available on PI SharePoint: (for e.g. utilisation time, idle time etc). On-board data management systems are offered by most underground (U/G) mobile equipment manufacturers. These datasets (engine & performance data) are quite useful for proactive maintenance, troubleshooting and other maintenance-related decision-making purposes. However the challenge is that each of these systems is unique and proprietary, and does not use common communication protocols; hence data collection and analysis can become expensive and in some cases impossible. At the Sudbury Integrated Nickel Operation’s Ni Rim South mine (NRS), an intelligent solution has recently been developed and implemented in order to collect and analyse U/G mobile equipment data and then integrate the datasets into a single data historian. This has been possible in collaboration with Symboticware Inc., which is based in Sudbury (Ontario), Canada. At NRS, SYMBOT units have been installed on Load-Haul-Dump (LHD) trucks. Reliability of data transfer from LHDs to the data historian (OSIsoft’s PI) has been demonstrated successfully (Figures 21 and 22). Electronic notifications have now been enabled on four key engine parameters:

1) Engine Oil Pressure;
2) Engine RPM,
3) Engine Coolant Temp.; and
4) Engine Fuel Temperature.

Figure 21 – U/G Mining Mobile Equipment Monitoring – Ni Rim Mine
Ni Rim Mine Mobile Equipment Data and PI Notification – LHD Oil Pressure Low

(126 kPa, threshold is 130; Engine speed 1263 rpm)

Notification programmed on 4 Engine Parameters:


In our processing plants, (as well as for mining backfilling) a new instrumentation technology example which is providing us a key measurement that has been much more difficult, or impossible to get – in the past, is the CiDRA SONARtrac flow measurements. Figure 23, SONARtrac (Maron, R, O’Keefe, and Rothman 2010) is a new class of measurement with distinct application advantages – i.e. ability to primarily clamping onto most installed piping negating the requirement to cut and flange piping. As Maron presented to automining2010 (Chile) “Sonar array-based flow measurement technology was introduced into the mineral processing industry five years ago, and has since demonstrated significant usefulness and value in many difficult and critical flow monitoring applications. This robust non-invasive technology has become the standard for many companies in certain applications.” “Presented here is a summary of application experience, lessons learned, and best practices from installations worldwide. Highlighted applications include: cyclone feed flow measurement, measuring aerated flows for mass balance correction, stratification and sanding detection in horizontal slurry lines, slurry pipeline flow monitoring and leak detection. It will be shown how the basic volumetric flow rate, combined with the unique additional measurement of entrained air volume and the proper positioning of multiple meters can enable novel solutions to monitoring and control problems that are not possible with other flow technologies.” Figure 23 also shows a picture of a hydrocyclone feed installation at our Collahuasi Mill (Chile). Glencore have similar installations at Antapaccay (Peru), Antamina (Peru) and will also install at the new Mill, presently under construction, Las Bambas (Peru).
Flow Measurement – CiDRA SONARtrac
Ref: Christian O'Keefe
cokeefe@cidra.com

SONAR – A New Class of Meters with Distinct Application Advantages

VOLUMETRIC FLOW METERS

- Multivariable DP
- Vortex
- SONAR
- Ultrasonic
- Magneter
- Coriolis

Hydrocyclone feed line – as used by Collahuasi, Chile; Antamina, Peru etc.
Xstrata Cu - Standard Concentrator (5):
- Antapaccay, (Peru)
- Las Bambas, (Peru)

selected SONARtrac for the principal slurry lines

First meter installed in 2006

Figure 23 – Instrumentation Technology – Flow Measurement – CiDRA SONARtrac

Flow Measurement - In Circuit
Ref: Christian O’Keefe, cokeefe@cidra.com
Felix, Peacock, Huysamen, Thwaites

Platinum 2012: The Impact of Entrained Air and Enhanced Flow Measurements at the Eland Concentrator

Figure 24 compares volumetric flow readings from a electromagnetic meter to a CiDRA volumetric flow meter at a Glencore grinding circuit in South Africa. Clearly, more accurate measurements allow improved control, but also start to become very valuable in metal accounting. The South African installation, presented at Platinum 2012 (O’Keefe et al 2012), also includes flow
measurements on concentrate products, an area that has been particularly difficult in the past, partly due to air entrainment. Note mass flow will still require a density meter and installation guidelines must be strictly adhered to in order to obtain the best accuracies, for both flow and density. As you can appreciate from this example, the best, most accurate instrument measurement will help a great deal in achieving ‘Operational Performance Excellence.’ Less variability in measurement allows a higher degree of control, or even basic regulatory control where previously no control was possible.

Have we endorsed this ‘new’ measurement technology? Figure 25 summarises that approx. 140 SONARtrac volumetric flow meters have been installed at approx. 16 Glencore mineral processing, mining facilities in the last decade.

140 SONARtracs at 16 Glencore Facilities

- Alumbrera, Argentina
- Antamina, Peru
- Antapaccay, Peru
- Brunswick Mine, Canada
- CEZinc Refinery, Canada
- Collahuasi, Chile
- Eland Platinum, South Africa
- Ernest Henry, Australia
- Horne, Canada
- Las Bambas, Peru
- Mt. Isa, Australia
- Perseverance Mine, Canada
- Tintaya, Peru
- Sudbury Ni Rim South, Canada
- Sudbury Smelter, Canada
- Glencore Coal, Australia

From Hydrocyclone feeds, to concentrate lines, to transfer
Pipelines, backfill lines and tailings lines ....

Figure 25 – Instrumentation Technology – 140 SONARtracs installed at 16 Glencore Facilities

OPERATIONAL PERFORMANCE EXCELLENCE

How do we define Operational Performance Excellence? “Business optimisation, by definition, requires a focus on operational performance excellence, with a focus on 4 major areas” with one being Control Excellence (AMR/Gartner 2010). “Closed loop production and business control (being able to use real-time feedback to better run the operation) will continue to be an important goal for clients.”

How, you may ask, does this relate to Mineral Processing Plants? To illustrate I will pick three key areas, but it is important to note that there are other very important areas as well, such as: grinding, filtering, drying, metal accounting etc. Let us start the discussion with flotation level control, as this area usually presents many opportunities for our plants.

FLOTATION LEVEL CONTROL

Flotation is a complex subject and has many facets to its optimal control, making it very interesting to both the Mill Metallurgist and our Control Engineers. (Akzo Nobel): “In an ideal situation, collectors should absorb selectively on the valuable minerals, and depressants should absorb selectively on the unwanted gangue minerals. Unfortunately, this is almost never the case and the right combination of collectors and depressants require the dedicated chemicals; and a lot of fine-tuning in the flotation process.”
Flotation is so fundamental (Thwaites 2007, plus numerous others) to the separation of copper, zinc, nickel and lead sulphides. Therefore it plays a very important part to the Glencore operations. Optimum flotation performance is reliant on good level control, air sparging and flow control, as well as precise chemical additions and mineral liberation. Significant opportunities are found in flotation operations by attention to these fundamental controls. Flotation control has, should have, and will continue to have, a lot of attention from plant Metallurgists and Control Engineers (Thwaites, 1983 and 1986; Flintoff and Mular, 1992; Gillis, 2000; Shean and Cilliers, 2011; and Hodouin, 2011). It is the process area of significant upgrading of commodity minerals / metals.

In the operation of a flotation cell, Figure 26, it is absolutely necessary:

1. Always Prevent Flooding … or empty banks &
2. Maintain an Accurate, responsive Pulp Level, on a (1) second basis, thereby allowing adequate control, then optimisation, of the setpoint.

Note, pulp level is the variable known to the Operator and is usually highly correlated to mass pull and mineral recovery. Recovery can be calculated on typically a 15 min. basis for metallurgical control (Thwaites 1983 and 1986) and mass pull can be measured on a 1 min. basis, from flotation cameras measuring froth velocity (Jin et al 2013).

**Flotation Objective?**

1. Always Prevent Flooding … or empty banks &
2. Maintain an Accurate, responsive Pulp Level, on a (1) second basis, thereby allowing control, then optimisation, of the setpoint.

*Note, pulp level is the variable known to the Operator and is usually correlated to mass pull and recovery.*

As we have discussed earlier, and shown in Figure 27, tuning can play a big role, and this figure shows the very nice effect of retuning, resulting in a 56% reduction in variability and the elimination of bias - by applying ‘integral action’ to the control loop. These results were obtained in a large flotation plant. Without it, (please note) the Operators were required to memorise the bias and apply it consistently to their setpoints! Several such loops were noted to be the same, and each were resolved by re-tuning. We did not ask the Operators how they handled this, or even knew about it!
Control Loop Improvement
(Flotation level controller)

...regulatory control, bias removal...

Several loops were updated.

Typical results:

• Reduction of variability
• Elimination of bias
  – *virtual absence of Integral action*
• Smoother control action
• KPI’s (key performance indicators) at target

Figure 27 – Control Loop Improvement – Flotation Level Control, from Re-Tuning

Figure 28 summarises our view of ‘Operational Performance Excellence’ as applied to flotation level control – often an area for huge gains in flotation plants. Note, I often relate back to engine fuel management / control – as a comparative illustration and the impact on performance with the wrong fuel to air ratio.

Flotation Level Control - Best Practices Example
- Operational Excellence

1. Basic Level Device
2. Level Control Tuning (PID Feedback)
3. Split Range Actuation (2 Valves)
4. Smart Positioner (Valve opening Feedback)
5. Level Control Tuning (+ Feedforward)
6. Surge Tank Control Tuning
7. Level Setpoint Optimization: e.g. Froth Velocity Controller
8. Best Practices – Control to Metallurgy ($$) Flotation Level Control

Flotation Cell Level Control

Reduction: 56% & Bias Elimination

Before:

STD DEV: 2.7%

After:

STD DEV: 6.0%

56% Reduction of STD deviation
100% Reduction of average deviation

Bias elimination

Figure 28 – Flotation Level Control – Best Practices Example Illustrating Operational Excellence

For flotation level control eight key steps are shown to achieve best practices. Prior to tuning, the condition of the measurement device, and the actuation, needs to be assessed and addressed – as appropriate. Not all flotation level (displacement) floats are the same, with many sticking (in their guides), with unacceptable friction. Many utilise ball floats (rounded bottoms) which are more susceptible to density variations and cracking at the top of the float – letting water in and affecting the mass of the float. Our best practices are noted in the XPSFloat™, which is available both within and outside of Glencore; and also through Endress and Hauser (E+H). Proper engineering is required on the flotation level measurement device. After the basic level device and retuning, flotation level performance can be further...
enhanced by utilising a feedforward term in the controller, to address upstream disturbance. While easily done in our control systems (and applied by Mintek’s FloatStar, Schubert et al 1999) it is generally not widely practiced and rarely implemented in new plant commissioning. Schubert et al (1999) on FloatStar “Mintek has developed a level-control system, FloatStar, for use in flotation circuits. Instead of controlling levels separately in each unit, the controller monitors levels throughout the circuit. It can thus take account of the global effects of any control actions.”

Like the level measurement, an even tougher challenge is the engineering of the final control element (i.e. often dart valves) to handle control in the operating envelope. Often two dart valves are installed, therefore split range control (Figure 28 and Figure 29) is a further enhancement as well as smart positioner feedback – allowing the controller to know that one, or both, actuators are saturated, or closed. Surge tank control and ultimately level setpoint optimisation will ultimately allow closed metallurgical control (Thwaites 1983 and 1986; Jin et al 2013).

Figure 29 – Feed Forward and Split Range Control for 2 Flotation Darts

In most flotation plants it makes sense to utilise froth velocity cameras (typically providing measurement at a 1 minute basis, as shown in Figure 30) to “infer” mass pull (related to recovery) in between updates from the online XRF (X Ray Fluorescence spectrometer). Froth velocity can control
regulatory PID controllers for both air and level – as best practised at Escondida, Chile. However we must also pay detailed attention to flotation chemical additions: pH modifiers, frother, activators, collectors and depressants. Let’s take a closer look at reagent control, as related to Operational Performance Excellence.

**REAGENT CONTROL**

In Figure 31 and as observed in our industry, we see a multitude of different approaches to chemical addition and control, so like flotation pulp level control it is worth identifying some key aspects of flotation reagent control best practices. Chemical metering is an excellent application for coriolis flow and density measurement – at the highest possible accuracy i.e. 0.1% measurement error. I have recently been into one of our new Mineral Processing plants and observed that there were no measurements on the chemical addition, there were minimal addition points (minimal staged additions), no automatic ratio to metal units, and finally a poor setup for measuring / checking the actual flowrates. Consequently, and with also no flotation air flows to adjust, the only variable left for the Operator control was flotation pulp levels! We have learnt over the years (Thwaites 1983, 1986) that air and levels generally move the flotation process outcome along the grade / recovery curve, while collector chemical changes move the process outcome onto different grade / recovery curves.

**Figure 31 – Reagent Dosing and Measurements. Are You Using Coriolis?**

Chemicals are one of our (more expensive) consumables, and as such should have the highest precision and accuracy on the measurement. Often they do not!
Flotation Reagent Control -
Best Practices – Operational Excellence Example:

Remember - Metallurgical (Met.) Control is the goal

1. Basic Measurement
   Mag meter, or Coriolis, or pulsed device?

2. Specialty
   (pure, undiluted, pulsed injection) collectors?

3. Flow Control tuning (eng. Units)

4. Ratio Control g/Tonne

5. Met. Control (Ratio) GMU g/Metal Unit

6. Met. Control with strategies for start-up, shutdown, & short stoppages, or losses in XRF data

7. Met. Control with feedback Optimization (Mass Pull; Analyzer recovery or froth quality)

8. Best Practices
   Flotation reagent Control
   => Optimum Metallurgy ($$) + 25% lower reagent costs

Always use Coriolis for HIGHEST Precision, Accuracy – this is your consumable!

Figure 32 – Flotation Reagent Control – Best Practices, Operational Performance Excellence Example

Use of chemical metering pumps (Figure 32) allows very fine and accurate – staged additions, but they must be measured and automatically controlled for best practices; and they should pump into (low) pressurised lines, allowing instantaneous update / changes in flow at the discharge point. The discharge point should be open, and above a funnel, allowing easy visualisation and measurement for the field Operators. Best practices flotation reagent control (Figure 32) can then be summarised (as we see it) as follows:

1. Basic measurement of chemical – coriolis meter gives the best accuracy, and measures the density;
2. Specialty collectors (like AEROPHINE 3418A – Thwaites 1983 and 1986) allow much more precise control of flotation;
3. Use a local PID control loop for flow control;
4. Cascade feed tonnage and automatically control the reagent setpoint in g/tonne ratios;
5. Upgrade the cascade ratio to GMU (g/metal unit) and automate this ratio addition – updating every 15 mins. (while noting that this is still feedforward control);
6. Enhance the Metallurgical control with strategies for start-up and shutdowns, and short stoppages (like rodding etc.);
7. Enhance Metallurgical control with feedback trim based upon actual mass pull, or recovery update, or froth quality (from froth flotation cameras);
8. Best practices flotation reagent control will lead to ‘Optimum Metallurgy’ and can save up to 25% in reagent costs (Thwaites 1983 and 1986).

Much more attention needs to be paid to the chemical additions in our mineral processing plants. (See also Shean and Cilliers 2011; and Hodouin 2011).

From flotation we soon arrive at thickening, whether concentrate or tailings – another area lacking current measurement technologies, lacking good controls and lacking the right level of automation.
THICKENER CONTROL

Thickener controls are not easy and are rarely setup properly following new process/plant commissioning and can lead to overloading, failure (Villanueva, Garcia, 2013) and unexpected downtime. Furthermore, key measurements have been challenging, or not even implemented. Cortés and Cerda (2010) reported, “The Concentrator of División Codelco Norte, Chile has nine tailings thickeners, which are used to thicken the tailings and reclaim water from them. Several control strategies, including expert control, have been implemented in the thickener, but the results were not satisfactory, therefore the thickening process continued to run in manual operation.”

Are your thickeners in automatic control? Do you add flocculant based upon mass flow into the thickener? Did you know that E+H coriolis meters on flocculant measurement can also identify lower viscosity, identifying when you may be pumping just water in your reagent stream? Do you operate the thickener on bed mass measurement and do you maintain a basic, consistent bed level with minimal loss of mineral to the overflow? Do you measure the quality (turbidity) of the overflow?

Figure 33 by S. Rigling (E+H) is a nice illustration of key measurements available for thickeners. Bed pressure can be measured, allowing (real time) calculation of inventory when the right instrument is correctly located in the bottom cone. This should be used to control the underflow pumps (speed control) and their removal of material from the thickener. Bed level can usually be measured (by a sonar based instrument) on a stable operation – one under control, and should be used to trim the chemical addition ratio; however bed level is still difficult to measure especially on an upset process! Resulting underflow density should also be measured, as well as underflow flow. Overflow clarity is a good indication/warning of process problems, and mineral loss! Automatic rake arm lifting should be controlled to torque – and often is.

E&H: Typical positioning of a thickener’s critical parameter measurement devices

S. Rigling – E+H Australia; Synergy Canada

Figure 33 – E+H: Typical Positioning of a Thickener’s Critical Parameter Measurement Devices
Cortés and Cerda (2010) concluded, “The Underflow solid average percent has been reduced by 22.3% in variability but a similar mean value.” “Implementation of this control strategy in all the thickeners of the concentrator will increase the Underflow Solid average percent by 0.5% in the thicker which also represents 2.8% of water used by the Concentrator for processing per day for each Thick.”

Good flotation and thickener performance will have an impact on downstream processes – like roasting, Figure 34. Roasting performance can also significantly be improved following adherence to variability reduction efforts, and best practices process control (Thwaites 1993). For example improved feed control will lead to better bed temperature control e.g. to a standard deviation of 1.80, and can then allow bed temperature optimisation to other roaster constraints – like top temperature. Optimising bed temperature control at Kidd resulted in an additional throughput of 4%. The figure shows a (modern, recently constructed) roaster under manual bed temperature control.

Figure 34 – Roasting Need – For Good Process Control: Manual Bed Temperature Control Shown

ASSET AND PERFORMANCE MONITORING

Asset and performance monitoring is crucial if we are going to fully realise the optimum from the big investments which are made in mining and mineral processing plants and operations. At the instrument level this is far more possible now, than it was three decades ago. Figure 35, (Mujica et al 2005), identified a key need for Milling operations, following the Concentrator benchmarking study: “The first need is to solve instrumentation problems by means of predictive maintenance and fault detection. The use of “hard technologies” such as smart instrumentation Fieldbuses and ‘soft’ technologies, such as multivariate online analysis shows a great potential on this topic.” E+H is but one supplier offering a comprehensive instrument support and documentation system which could be more widely used (and not just for their instrumentation).
Plant Asset Monitoring (at the Instrument level)

AMIRA P893 (2005) Benchmark Study – Section 7 Future Needs:

“The first need is to solve instrumentation problems by means of predictive maintenance and fault detection. The use of “hard technologies” such as smart instrumentation Fieldbuses and “soft” technologies, such as multivariate online analysis shows a great potential on this topic.”

- Leverage intelligence in device:
  - Key is use of some information bus (HART, Proftbus, FF) to access parameters
  - Want to integrate all devices

- Desired benefits:
  - Increased performance
  - Higher online time
  - Assets properly configured and calibrated
  - Decreased cost
  - Reduce unnecessary work
  - Reduce effort to accomplish a task

- Two main technologies:
  - EDDL
  - FDT

- Functions in asset monitoring:
  - Configuration; Calibration
  - Performance monitoring & Troubleshooting

Figure 35 – Plant Asset Monitoring (at the Instrument Level) - E+H and AMIRA P893 Study

Figure 36 – illustrates very important asset monitoring capabilities in DeltaV (Emerson) and ABB control systems. Control loop diagnostic conditions monitored can include the following, as documented by the current ABB control system:

- Final Control Element (FCE) Stiction, Size & Leakage;
- Excessive FCE Action;
- Tuning Problem;
- Loop Oscillations;
- External Disturbances;
- Loop Nonlinearity;
- Data Reliability;
- Insufficient Travel;
- No Response to Signal Change;
- Noisy or Unstable Output;
- Slugish Response;
- Valve Body/Seat Wear.

Yet we see very little actual usage of these important capabilities, unlike the extensive process monitoring which we (Glencore, Vale, Anglo etc.) typically do with the widespread and well known OSIsoft’s PI data historian system – Figures 8 and 37. I am sure that most readers can relate to the ‘Check Engine’ light found on all modern vehicles!

Monitoring of the control assets, whether the plant has 100, 600 or over 1000 control loops is extremely important, especially if we want to immediately deal with poor controller performance, or know as soon as a key control loop degrades – requiring retuning, instrument maintenance or gain scheduling.
Control System Loop Diagnostics
(e.g. ABB, and DeltaV InSight, Yokagawa??)

Diagnostics .... are you using them?

Diagnostic Conditions Monitored are:

- Final Control Element (FCE) Stiction, Size & Leakage
- Excessive FCE Action
- Tuning Problem
- Loop Oscillations
- External Disturbances
- Loop Nonlinearity
- Data Reliability
- Insufficient Travel
- No Response to Signal Change
- Noisy or Unstable Output
- Sluggish Response
- Valve Body/Seat Wear

Figure 36 – Control System Diagnostics e.g. ABB, DeltaV, Yokagawa etc.

Process (& Plant) Monitoring
OSIsoft PI System 2010, 2012 etc.

Used extensively by GlencoreXstrata, Vale, Anglo (S. America) etc.

Figure 37 – Process and Plant Monitoring by OSIsoft PI Systems
Outside of the control system, there are few options and we presently see the choice as either Honeywell’s Control Performance Monitor (CPM) – Figure 38 or ExperTune’s Triage. While (significant) further investment is required for either product, there ultimately is a business case to the operation in continuously monitoring the minute by minute performance of ALL the Plant’s critical control loops, as we monitor our processes using OSIsoft’s PI systems. For example, “CPM can enable a sustainable workflow that enables tracking of maintenance efforts as well as archiving maintenance history on each loop.” See Honeywell, Jin et al (2013) and Ruel (2010) for further information and discussion.

Control Performance Monitor (CPM) (Matrikon/Honeywell) is...

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**a control performance improvement product that can diagnose causes of poor control at all levels of the plant control hierarchy:**

<table>
<thead>
<tr>
<th>Plant Control</th>
<th>Control Performance Monitor (CPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Process Control</td>
<td>• MONITORS advanced control assets for poor performance &amp; provides detailed diagnoses</td>
</tr>
<tr>
<td>Analyzers &amp; Online Inferentials</td>
<td>• MONITORS regulatory control assets for poor performance &amp; provides detailed diagnoses</td>
</tr>
<tr>
<td>Regulatory Control</td>
<td>• PROVIDES TOOLS detecting instrument freezes, data spikes, rate of change alarms and high-low limit violations</td>
</tr>
<tr>
<td>Instrumentation Layer</td>
<td></td>
</tr>
</tbody>
</table>

CPM can enable a sustainable workflow that enables tracking of maintenance efforts as well as archiving maintenance history on each loop.

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Figure 38 – Control Performance Monitor (CPM) by Honeywell / Matrikon

UK’s Perceptive Engineering’s Focus / Vision (Dr. D. Sandoz, D.J. Lovett)

Integrated Condition Monitoring & Advanced Process Control

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Figure 39 – UK’s Perceptive Engineering’s Focus / Vision (2003) – Integrated Condition Monitoring & APC

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Figure 39 - Many years ago, Sandoz (2003) presented this (Perceptive Engineering’s) important view/vision of asset monitoring which integrated condition monitoring (and failure / fault diagnostics) with advanced process control. In this Figure, Multivariate Statistical tools like PCA/PLS (Principle Component Analysis / Projection to Latent Structures, or Partial Least Squares), and their models, are run in real time, as the process operates, as early monitoring condition monitors - predicting key measurements, comparing them to the actual measurements and squaring the ensuing errors to identify any break in expected performance.


**Furnace Hearth Integrity Monitor by PCA/PLS**

(Xstrata Ni, Sudbury Ni Smelter)

4th Furnace Integrity Monitor application using the PCA/PLS technology

- Publication of initial furnace integrity monitor application at Kidd Cu Smelter (Nelson et al., Cu2007)
- Integrity monitor for tapholes in operation since 2009:
  - Tapholes are high wear, high risk area that gets a lot of attention
- Hearth monitoring beyond individual thermocouple alarms desired:
  - Hearth monitor alerts technical personnel before individual thermocouple alarms
  - Potential issues: cooling fan problems, thinning of bottom buildup, matte

Figure 40 – Furnace Hearth Integrity Monitor by PCA/PLS (Sudbury Ni Smelter)

We have used such systems in our Pyrometallurgical operations (Figure 40) robustly and successfully (Thwaites et al 2004; Nelson et al 2007) now for many years. They are very robust and can cope well with instrument signal losses. Unfortunately we have seen fewer applications in our Mineral processing plants, although interesting (off-line) prior work was done by Hodouin et al (1993). “On the industrial data which were processed, PCA and PLS were able to disclose regions of consistent operations and times at which changes occurred for both the grinding and flotation circuit. It was much more difficult to pick out such regions and changes by inspecting the raw data.” “Predictive models for both the grinding and flotation sections of the plant were developed using PLS. The observed relationships were, for the most part, quite consistent with prior knowledge about their behaviours, despite the high level of noise, a large number of missing input variables, and some raw data inconsistencies. These models could be used to gain improved understanding or to infer infrequently measured variables.” In the present market, Perceptive Engineering (UK), ProSensus (Canada) and Contac (Chile) all have software products to further support interested customers in this fascinating area.

Figure 41 and 42. In fact Sandoz’s (2003) vision (presented in Figure 39) has now materialised (Zamora, et al 2010) – coming from the AMIRA P893 benchmarking study – a comprehensive control
monitoring centre, on top of the Plant and local control rooms but in the city. One of the earliest of these, initially focused on the Codelco plants was in Santiago, Chile. The original focus was automation deployment and support covering multiple sites and utilising key Honeywell resources – more available in the city environment. Once established, the focus expanded to also include asset monitoring:

a) Providing access/network to many service providers for remote servicing/configuration and on demand analysis & diagnostics; and also
b) providing a Core Honeywell team ensuring success;
c) Adding real-time expert monitoring for fixed equipment.

Kairos Mining (Chile) – A Comprehensive Approach to Sustained Benefits in Automation

CMP 2010 PAPER #27 by: Giselle Schifferli (and C. Zamora)

Original Focus:
- Automation deployment & support
- Multiple sites supported from Santiago, Chile

Focus Expanded for:
- Asset Management

Figure 41 – Kairos Mining (Chile) – A Comprehensive Approach to Sustainable Benefits in Automation

Zamora et al (2010) “Considering that process automation is a key enabler to business performance improvement, sustaining effective performance benefits over time becomes essential.” “A new concept in process automation is proposed through the addition of a new control loop based on performance analysis methodology which is intended to feedback process and automation operation information to system and process specialists, allowing for continuous manufacturing process improvement and sustainable productions benefits through effectual control strategies.” “A remote support centre can play a key role in the delivery of such services..., as an enabler for plant operational practices change.” It must be noted that this centre complements the local control room Operator and local control room functions, as I observed them.
Honeywell Remote Support Centre – Kairos Mining, Santiago, Chile

Original Focus:
- Automation deployment & support
- Multiple sites supported from Santiago

Expanded for Asset Management:
- Provide access/network to many service providers:
  - remote servicing/configuration
  - on demand analysis & diagnostics
- Core Honeywell team ensures success
- Adding real-time expert monitoring for fixed equipment

Collahuasi
Codelco
- Chuquicamata
- El Teniente
- Andina
- Salvador
- Ministro Hales
Glencore Xstrata, AngloAmerican
Casarones

Figure 42 – Honeywell Remote Support Centre - Kairos Mining Santiago, Chile

At the other end of the globe, in Australia, Figure 43 we can also see a similar approach from Rio Tinto: “13 March, 2014 Rio Tinto has unveiled the latest component of its Mine of the Future program - the Processing Centre of Excellence. Based in Brisbane, Rio says this "is a world first (?), state-of-the-art facility that enhances monitoring and operational performance by examining in real time processing data from several Rio Tinto operations spread across the globe". Operated by a team in Brisbane, that will provide processing solutions and initiatives to mine sites in Mongolia (at Oyu Tolgoi), the US (at Kennecott), and across Australia (at five different sites). A massive interactive screen will show, and analyse, technical data in real time, "allowing processing improvements to be immediately introduced and operational performance to be optimised," the miner said. Early trials have already led to improvements such as adjusting the flotation process for gold and copper recovery at Oyu Tolgoi in Mongolia. Speaking at the launch today, Rio CEO Sam Walsh said “the Processing Centre of Excellence (PEC) marks another important step in the rollout of our exciting Mine of the Future program.”

Figure 43 – Control Centre – Processing Centre of Excellence (Rio Tinto)
Shortly thereafter, Mar. 14th, 2014, The Australian (Chambers) reported: “Big data saving us $90m: Rio boss.” “MASSES of data generated by Rio Tinto's plants, drill rigs and automated trucks have become a key part of the mining giant's productivity drive, with a new Brisbane process centre already reducing costs by $US80 million ($90m). Rio chief Sam Walsh said analysis of so-called big data at the "process excellence centre" opened yesterday had already more than paid itself back.”

CONCLUSIONS AND KEYNOTE WRAP-UP, RECOMMENDATIONS

The mining industry uses many types of mineral and metallurgical plants to produce saleable product from ore mined. Plant design history has left current operations with a mixture of manual operation and various forms of automated process controls. Consequently, we typically see high variability in the continuous operations together with a shortfall in the attainment of full capacity, or higher utilisation of consumables.

At a level of best practice, ‘Operational Performance Excellence’ focuses on process control, using automation and control systems to deliver process optimisation. This more sophisticated delivery is a great deal more difficult than the first stage of equipment selection / installation. It includes the appropriate selection of the right instrumentation, control system, key process knowledge, individuals with a solid control engineering background / experience, and the essential backing / support of the operations management team together leading to higher value delivery. Robust solutions can be realised, considerably minimising process variation, thus leading to process optimisation. This approach results in an easier, efficient and safer process while providing considerable returns for the plant owners.

For those of us working in Mineral Processing plants, working on new process and plant design, and those responsible for applying technology, I say we can, we MUST, do MUCH MORE and therefore become More Efficient.

The Process Automation area remains a major opportunity for improved efficiency, improved milling, minimising tailings losses and other costs. Process Control should be further applied to help us run consistently to our process constraints, in effect maximising the process efficiency and process utilisation. However we need more champions, and more Control Engineers in our Plants as well as the very important Operations’ Management support.

Would you run a business without a Financial Accountant? Let’s see more Control Engineers and more process control, using automation in our industry.

My Recommendations To You All:

– Instrumentations & Instrumentation Solutions ….
  – Make them work for you and use more of the great instrumentation currently available.

– Control Systems …. as you might now appreciate, I am a strong advocate of Plant DCS, with the right, trained resources.
  – Push your control system to keep delivering for you, reducing variability;
  – Use more feedforward, cascade controls & ensure controllers are tuned, functioning at the regulatory level;
  – Seek input from your supplier and ensure you use what the system can do;
  – Automate tedious and repetitive, known tasks;
  – Focus on optimisation and seek better business performance.
– Employ one or more Control Engineers to complement your Operations & Instrumentation Teams.
– Use Asset, Performance Monitoring tools to be more proactive. (Think of your ‘Check Engine’ light.)
– Analyze, Act and ensure data becomes knowledge for Business ($$) actions – *always*.


**ACKNOWLEDGEMENTS**

I particularly would like to acknowledge the +44 Process Control Engineers whom I have, and had, the privilege of working with, leading. Each have had their own interesting, unique backgrounds and extensive contributions, several of which have been discussed in this paper. In addition to my Senior Group members: A. Hyde, P. Nelson and R. Bose, and my core group, I also acknowledge my XPS colleagues, including: D. Fragomeni, N. Lotter, G. Marrs and Glencore for permission to share this work and publish this paper.

I acknowledge Atlas Copco and the Canadian Mining & Metallurgical (CMMF) Foundation, as sponsors of the CIM Distinguished Lecturer program as well of course – those whom supported my nomination for the 2012-13 award, including the national CMP – Canadian Mineral Processors.

Lastly Canada has been a terrific place to work, starting for me in 1979 – in underground mining, then in milling at Kidd Creek with Texasgulf and roasting, hydrometallurgy at the Kidd Zinc Plant; before moving on to the Nikkelverk Refinery, Norway; and returning to the (then new) Technology Centre at Falconbridge. Canada has been, and continues to be, a good base for (XPS) Consulting and Testwork Services business in the global mining industry, and Glencore brings further interesting opportunities, challenges.

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