Towards an integrated framework for asset and process health monitoring and optimisation on a milling circuit

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Abstract

Mining companies are increasingly faced with the challenge of reducing operating costs while maximising throughput and profitability. At the same time, the grade and quality of treated ores are becoming poorer and more variable, resulting in sub-optimal process performance.

It is now widely accepted that strategies to drive operational goals must revolve around improving plant availability, reliability and process efficiency. In particular, progress in plant automation and control systems has seen a trend towards unified frameworks for control and optimisation of mineral processing plants. These frameworks seek to seamlessly integrate different roles and tasks involved in process operations – IT, automation, plant maintenance and operations.

An integrated solution framework for reducing process variability, increasing process efficiencies and maximising plant availability and reliability is discussed within the context of a typical milling circuit. The framework exploits a real-time analysis “gap” evident in production operations that prevents timeous identification of equipment and process failures. This is achieved by leveraging predictive analytics for equipment health monitoring, control loop monitoring and advanced regulatory control solutions towards enhanced process performance, improved asset management and regulatory compliance. The framework provides for early and actionable warnings on equipment and process degradation using real-time operational data.

Resolving these problems can potentially avoid unplanned downtimes, process instabilities and other operational surprises, thus ensuring optimal plant throughput and optimal process behaviour for improved recoveries. Integrating control systems and plant automation with advanced analytics to analyse and optimise processes enables operations to achieve reductions in the variability of key process parameters. In addition, early detection of equipment malfunction or sub-optimal process conditions leads to improved equipment availability and reliability. Ultimately, these operational gains reflect in profitability because of plant throughput and recovery gains. These benefits are demonstrated using data from a South African gold-mining operation, where such an integrated asset and process-health monitoring framework for process optimisation has been implemented.

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Introduction

The changing landscape of gold mining and processing presents many challenges that threaten sustainability of existing (marginal) operations as well as deter investment in new projects. As existing “shallow” ore resources become depleted, mining operations are increasingly treating low-grade ores with complex and randomly variable mineralogical characteristics. For example, in South Africa, historically one of the major gold producers, the average grade of ore treated has been decreasing from averages above 4.5 – 5 g/t to current grades averaging less than 3 g/t within a decade, as shown in Figure 1. Moreover, lower tonnages are being treated as a result of the narrowing of the available resource base. Also, the regulatory framework has tightened over the years due to heightened concerns on the safety, health and environmental impacts of mining and related activities.

Figure 1 Volumes of treated gold ore (bar plot) and corresponding grades (line with square markers) in South Africa between 2002 and 2011 (Chamber of Mines, 2012).

It is widely acknowledged that, to achieve business goals in mining operations, focus must be on maximising throughput and increasing recovery rates. Although there has been progress in development of innovative mineral processing technology used for ore beneficiation and metal extraction, operational improvements are still seen as critical in advancing competitiveness in operations. These include process efficiencies, asset reliability and availability. The importance of this perspective has been captured in various initiatives, such as “plant of the future,” intelligent plant,” and “smart plant.” At the core of these concepts is the integration of the management and execution of activities that affect production that has now been made possible because of maturity of automation technologies, which previously did not yield expected improvement gains in mineral processing and, therefore, were considered unreliable.

In this paper, a strategy for optimising mill circuit performance is discussed. The approach is based on integrating asset and process-health monitoring and diagnostics. Asset management is critical in ensuring availability of critical equipment as well as its performance. In particular, potential problems can be detected before they occur or worsen to avoid “operational surprises,” allowing for planning of maintenance activities. Using advanced predictive analytics to predict failure and facilitate maintenance guarantees equipment availability and, therefore, maximum throughput. Asset management also includes monitoring performance of various controllers used for process stabilisation, a prerequisite for process optimisation. Process monitoring is useful for assessing, analysing, and tracking observed process performance. Control actions are implemented to reduce deviations between measured performance and plant targets. In milling circuits, key objectives that guide monitoring include (Drunick and Perry, 2005):

- Process stabilisation: Stable process behavior is necessary before implementing continuous process-improvement strategies. In the case of the milling circuit, achieving consistent grind quality requires minimal fluctuations in operating conditions, such as flow rates, mill discharge density and cyclone feed pressures.

- Throughput maximisation: Increased throughput of concentrated ore contributes greatly towards achieving business goals. Therefore, parameters and actions that impact plant availability and utilisation require monitoring to maximise throughput. For example, mill overloading can have significant effect on production (Powell et al., 2001).

- Optimal energy use: Grinding is an energy-intensive process, and the cost of grinding typically represents about 50% of a concentrator’s total operating costs (Pomerlau et al., 2000). Typically, less than 10% of the total electrical energy applied is used in the actual size reduction of ore. Consequently, it is essential that grinding circuits be run as efficiently as possible to minimise energy costs (Rajamani and Herbst, 1991).
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Commonly, a real-time analysis “gap” between analysis phase (data collection, analysis and decision making) and productivity improvements (resulting from process improvement, plant availability, equipment reliability and recovery gains) is evident in production operations that prevents timeous identification of emerging equipment and process failures, resulting in sub-optimal performance. Integrating control systems, plant automation and advanced analytics to analyse and optimise processes enables operations to:

→ Rapidly detect and understand causes of variation in key process parameters through monitoring performance with automated cause diagnostics
→ Turn insight into actions and reduce variability through real-time analytics for stabilisation of regulatory control
→ Push performance to design or specification limits, minimising energy use per unit of ore treated via real-time set-point optimisation and advanced process control
→ Monitor performance across the installed asset base for efficiency and reliability of grinding mills, pumps and motors through advanced warning of performance degradation or impending problems.

In the following section, the components underlying the integrated asset and process-health monitoring framework for mining operations, namely equipment monitoring, control loop monitoring and advanced process control solutions, are discussed in some detail.

Methodology

The proposed integrated approach to asset and process-health monitoring and performance optimisation is built around predictive analytics and diagnostics for equipment monitoring as well as plant-wide control and optimisation using advanced process control solutions and control loop monitoring.

Equipment-health monitoring with similarity-based modeling

Similarity-based modeling (SBM) is a data-based statistical modeling technique that is used to predict imminent equipment failure using a similarity measure evaluated between pairs of observations and manipulation of a matrix containing historical training vectors characterising equipment behaviour under normal or fault-free conditions (Weiglerich, 2004). Let \( X(t) \) be a set of measurements taken at time \( t \), that is:

\[
X(t) = [x_1(t), x_2(t), \ldots, x_d(t)]^T
\]  
(Equation 1)

where \( x_j(t) \) is a measurement from the \( j \)-th data source taken at time \( t \). The set of historical training vectors is then given by defining the matrix \( D \) according to:

\[
D = [X(t_1), X(t_2), \ldots, X(t_M)]
\]  
(Equation 2)

where \( M \) is the size of the training set. Given an input vector \( X \), the similarity operation evaluates estimated data source values \( X_\ast \) as follows:

\[
w = \frac{\tilde{w}}{\sum_{j=1}^{D} \tilde{w}(j)}
\]  
(Equation 3)

where

\[
w = (D^T \circ D)^{-1} \cdot (D^T \circ X) = G^{-1} \cdot A
\]  
(Equation 4)

where \( \circ \) is the similarity operation. The transform in Equation 4 involves two steps:

1. Similarity measure between the test vector and each of the training vectors to yield the similarity score vector \( A \); and,
2. Transforming the score vector into a set of weighting factors that subsequently are used to give an estimate that is a linear combination of the data entries in \( D \).

Ideally, the set of vectors constituting the reference or training matrix \( D \) is chosen such that the vectors characterise normal operating conditions of the monitored equipment. Moreover, these training vectors span its full dynamic variability when in operation.

The SBM approach possesses many desirable properties that are critical in detection of equipment damage or anomalous behavior. Specifically, SBM technology allows for detection and diagnosis of an incipient fault, as well as estimation of the rate of degradation and the severity of the fault. The approach is based on generating suitable features from observed multivariate sensor data (for example, spectra from...
high-frequency vibration data and calculated statistics thereof) and residual generation. The residuals then are used for fault detection and diagnosis using pattern recognition or logical rules, depending on the application.

In the milling circuit (described below), three items were configured to be monitored using an SBM-based software solution for condition monitoring: the mill motor, mill gearbox (including the lubrication system) and cyclone feed pump. A number of tags were identified and collected from the installed data historian. These included all the mill motor bearing and slip ring temperatures, jacking oil pressure measurements, pinion vibrations, pinion bearing temperatures, gearbox oil temperatures and pressure, cyclone pump gland service water pressure, cyclone feed pressure, pump current, mill discharge sump level and process water inflow, and pump vibration. Reference models were built using at least a month of data for each monitored asset.

Control Systems

Regulatory Control

Control systems are used to regulate the function of physical systems to ensure a desired state of operation. Feedback control is the most widely used control approach in which the state of a system is adjusted based on the difference between the system’s target and measured output. In general, control systems are designed to enhance system dynamics and stabilise the system through counteracting adverse effects, such as process disturbances. A schematic representation of a feedback-controlled process is shown in Figure 2.

For a PID controller, the modified control input to the process plant is obtained according to:

\[ u(t) = k_p e(t) + k_d \frac{d}{dt} e(t) + k_i \int_0^t e(\tau) d\tau \]

(Equation 5)

where \( e \) is the error signal and \( k_p, k_d \) and \( k_i \) are the proportional, derivative and integral gains. The response of the system is obtained using gain parameters tuned to enhance rapid system stability.

Control Loop Monitoring

Given the trend towards plant automation, it is not unusual to find hundreds if not thousands of control loops deployed on a modern mineral-processing plant. Control loops stabilise the system through counteracting adverse effects, such as disturbances that could result in the process deviating from set targets. It is, therefore, critical that control systems are performing as expected so as to guarantee predictable plant performance as a result of decreased process variation. Unfortunately, it is well-established that a large proportion of control loops perform poorly in practice, primarily as a result of oscillations arising from valve problems, bad controller tuning, oscillating load disturbances and other equipment- or design-related problems (Häggund, 1995). Poor control performance inevitably leads to increased process variability, affecting both the plant throughput and efficiency. In particular, poor control performance manifests itself through reduced pump efficiencies, increased equipment deterioration and reduced plant availability and reliability due to an increased rate at which equipment is in shutdown, surge tank spillages and other operational instabilities. Hence, automatic assessment and performance monitoring of control loops is critical in ensuring smooth and predictable plant behavior. Parameters of interest to identify underperforming PID loops or process and plant problems include the percentage time a loop exceeds specified range limits around the set point, operational range of the manipulated variable, time spent in a particular mode of control (i.e., manual, auto, cascade, and shutdown), configuration changes and loop travel index.

For the investigated milling circuit, the following control loops were monitored: mill discharge sump (cyclone feed) pump, mill load control, process water control valve to feed hopper, mill discharge sump process water inlet control valve and mill screen spray water.

Advanced Process Control

Ore beneficiation is a highly non-linear dynamic process that is difficult to completely characterise from first principles. Many of the critical material properties required for process control and performance monitoring in different unit operations are not measurable. Examples of these are ore grindability and texture in the grinding phase and surface properties, such as hydrophobicity in flotation circuits. Moreover, key operating parameters, such as mill hold-up, slurry rheology, particle-
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Size distribution and froth properties tend to be unreliable and measured inconsistently. Because of these process complexities and measurement uncertainties, simple control strategies based on PID control have not been generally successful in attempts to control the behavior of milling and flotation circuits. Control solutions that introduce additional control logic to accommodate complex process behavioral patterns have attracted interest in mineral processing because of their capacity to adequately respond to milling circuit disturbances. These advanced process control (APC) solutions, which include model predictive control (MPC), are increasingly becoming a necessary control layer in addition to conventional regulatory PID control (Smith, et al., 2004).

A schematic representation of the milling circuit considered in this paper is shown in Figure 3. Although the representation has been simplified for proprietary reasons, it suffices to highlight the integrated solution framework for asset-health monitoring and process optimisation. The APC solutions implemented for this milling circuit are discussed below.

**Figure 3** A simplified process-flow diagram of the feedback-controlled milling circuit as investigated in the paper. The numbered items correspond to the following implemented APC solutions: 1) Mill load control 2) Mill power-load optimiser 3) In-mill density estimation and control 4) Sump level range and density control 5) Cyclone feed control.

**Mill load control:** The rate of ore feed to the milling circuit typically is manipulated using a feeding mechanism installed on ore silos which feeds a conveyor belt that transfers the ore to the grinding circuit. To maintain a desired plant throughput, a mill load control system manipulates the set point of the mill feeder conveyor system. The conveyor covers a considerable distance before it reaches the mill. Therefore, a significant challenge in formulating an effective mill load control strategy is accounting for the time delay between the controller/actuator action and the process response. Further control complexities arise from the action of disturbance variables, such as ore size and feeder blockages. Using conventional PID control requires a decrease in the controller gain to counter the phase lags, resulting in a slow controller response. A model-based APC solution that uses a Smith-predictor to account for phase lags through inclusion of the effect of the dead time in the control action was implemented. This increases the aggressiveness of the controller, in addition to improving the robustness to other disturbances, such as changes in feed size.

**Mill power-load optimisation:** The relationship between mill power draw and load is well established – power draw increases with increasing load up to an optimum before decreasing, as depicted in Figure 4 (e.g. Morrell, 1996). This curve shifts horizontally and vertically over time as the grinding dynamics are influenced by changes in ball or rod media, mill liners and ore, among others. For a given set of conditions, the mill can be operated to achieve either maximum power draw (optimal grind quality) or maximum throughput. The mill under consideration targets an optimal grind quality and, therefore, an optimal operating point on the power-load curve in which the mill is not in the under-loaded or overloaded regime. Besides the poor grind quality, overload conditions increase ore residence time in the mill, which impedes mill discharge and other operational problems (Powell, et al., 2001; Smith, et al., 2004). In contrast, with a power-load controller, the mill operates close to the apex of the curve, giving a more efficient and cost-effective grinding. The APC solution uses a “search algorithm” that continuously “searches” for the top of the apex by making adjustments to the mill load set point and then estimating where on the power-load curve the mill currently is operating by monitoring the rate of change in the load and power parameters. With this strategy, the APC ensures optimal power usage as well as high grinding rate for better recoveries.
Figure 4: Variation of mill power draw as a function of mill load. The mill is considered operating efficiently at the optimal operating point (L_{optimal}) where the maximum power is available for optimal grinding rate and the media motion is most ideal. The two sides of this point on the power-load space represent two regions of suboptimal performance: underload zone and overload zone.

**In-mill density estimation and control:** The grinding performance of the mill load APC can be evaluated using the mill discharge density, which requires high frequency sampling of the density measurements. Unfortunately, such high frequency samples are not possible in many plants without automated densitometers. An in-mill density APC was developed that utilises an estimated in-mill density discharge to evaluate the mill grinding performance as well as control dilution water addition to the mill. The soft-sensor was developed using material balances around the mill and the discharge sump. Low-frequency manual density samples are used as correction factors for more accuracy. The density within the mill thus is controlled around a predefined set point via the mill dilution flow using the feedback of accurate real-time in-mill density estimates.

**Sump density range control and cyclone flow control:**
Sumps are used to regulate flow fluctuations from upstream processes that have an adverse effect on the performance of the downstream process. For example, fluctuations in the quality and flow rate of the cyclone feed will influence the efficiency of the split within the cyclone. Sump control is used to stabilise the flow rate and adjust the density of the feed to the cyclone. Base PID level control aims to control the level of the discharge sump around a fixed set-point. However, the strategy does not accommodate surges introduced in the flow. Hence, a surge in the sump has the effect of carrying through to the cyclone, affecting cyclone performance. To avoid these unwanted effects, we implemented an APC surge-control strategy where the controller gain is scheduled based on the level of performance within a pre-specified control band, say 40% - 60%. As soon as the level moves outside of this band, the controller responds aggressively to bring the level back within the band. Hence, upstream surges are prevented from cascading downstream, thus ensuring a stable flow and pressure to the cyclone. Because of the sump size, adjustments to the sump level control logic were necessary to avoid the sump overflowing or running empty in the presence of small process disturbances, which has the attendant negative impact on plant availability and pump performance degradation. In addition to flow stabilisation, the slurry density in the sump also can be controlled using the sump dilution water as the manipulated variable. As in the base PID control, the level in the sump is maintained at a stable set point, leaving the flow out of the sump as the only variable to manipulate the sump density. In effect, density is indirectly controlled, since direct control is not possible due to the limitations of the sump size. In order to stabilise both the flow out of the sump (manipulated variable) and the density (process variable), range control is employed for the density via an advanced regulatory control algorithm.

Where applicable, each APC solution was implemented on top of the already existing base-control layer and interacts with the PID layer by adjusting the process variable set points. The set points would be adjusted by operators, under normal circumstances. This not only simplifies the APC solution and implementation, but also allows for a fail-safe system in which the control logic automatically reverts to base-control layer should network connectivity or other communication problems occur. Heartbeat monitors are used to determine communication status between the APC machine and the base PID control layer implemented at a programmable logic controller level.
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Results and Discussion

In this section, illustrative results obtained from implementing a holistic, integrated approach for asset and process-health monitoring are presented and discussed.

Equipment Health Monitoring

Malfunctioning level sensor: Using control-loop monitoring analysis, it was observed that the PID loop associated with the cyclone feed pump was exceeding range limits around the set point while operating in auto or cascade mode (Figure 5).

![Figure 5](image)

**Figure 5** Control-loop performance overview for cyclone feed pump during the period when a malfunctioning level sensor was identified. Historically, the % limits exceeded were expected to be around 7%. However, there was a sudden jump to close to 8%, indicating an abnormal situation in the process, which was corroborated using the asset-health monitor.

During the transition from normal to abnormal condition, the manipulated variable (pump valve opening) also increased, as shown in Figure 6.

![Figure 6](image)

**Figure 6** A detailed view of the performance degradation observed in the pump using control-loop performance analysis. The top plot shows a wide distribution of the error (actual – set point, corresponding to the measured pump speed variable. In the bottom plot is a trend of the manipulated variable with time as the loop performance showed signs of degradation. Note the increase in the pump opening level around 16h00 hours.

In further analysing the pump operational history using the asset-health monitoring system (Figure 7), it can be seen that during this period the pump was operating at 100% speed when it was expected, given the loading conditions of the pump, to be operating at 80% speed. During the time the pump was being run at full capacity, it was found that a suction level was returning flat-line values, Figure 7(a) and (b). Upon investigating the issue, a malfunctioning level sensor was detected that was causing the level sensor to return flat-line values. This level indication, which is part of the pump-control system, caused the pump to operate at a higher speed than previously required for the same flow in order to maintain flow once the level dropped too low and the pump lacked net positive suction head for the given flow rate.

![Figure 7](image)

**Figure 7** (a) Pump output speed (b) Pump current. The zone within the dashed rectangle indicates the pump speed flat lining at 100% in (a) and a corresponding increase in the pump current in (b).

Failure to detect the malfunctioning level sensor would have resulted in the pump being run at higher speed than necessary given the loading conditions, potentially leading to increased wear-and-tear on the pump. Moreover, pump cavitation could have occurred, resulting in additional maintenance costs as well as increased plant downtime.

Lube Oil Pump Operational Issue: The SBM-based asset-health software solution detected that a lube oil flow and a lube oil inlet pressure to the mill gearbox were not operating as expected.
expected, as the mill came out of outage, Figure 8(a) and (b). Historically, the oil flow to the mill gearbox had an expected value of 160 l/min for the given operating conditions. However, values as high as 200 l/min were being observed, Figure 8(a). Simultaneously, the lube oil inlet pressure recorded values as high as 315 kPa compared to an expected operating value of 140 kPa.

This discrepancy initiated an investigation on the potential cause of the problem. It turned out that both the start-up lube oil pump and the main lube oil pump were running simultaneously. An operator had not switched off the start-up pump once steady state operation had been achieved. Running two lube oil pumps would have further strained operating costs, with the possibility of over-pressurisation and excessive flow of the lube oil system. This increased pressure and additional flow could have resulted in leakages of the system lube oil. If not corrected, this over-pressurisation could have caused the lube oil to slowly heat up and ultimately affect the lubricating quality of the oil. This could have caused damage to the gearbox bearings or gears, resulting in an unplanned outage of the mill and a subsequent loss of production.

Process Stabilisation and Optimisation

To highlight the performance of the APC solution and the improvement brought about as a result of the implementation, a before-and-after analysis of the control performance for two different time periods was done: one month with the APC solution running, and one month with the grinding circuit running with only base-layer PID control and manual operator intervention. The comparison results for the different APC solutions, which are summarised in Table 1, are discussed next.

Mill load control: As discussed previously, the advanced mill load controller implemented as part of the APC solution can accommodate the long time delay between control action and process response and can respond better to various operational disturbances that affect the mill feed. Figure 9 shows estimates of the load control error (difference between the mill load set point and the actual mill load) distributions when using PID and APC control strategies. It can be seen that the dispersion of values is narrower for the APC solution compared to PID control, suggesting tighter control around the set point. In each of the histograms, the tail on the left is related to feeder problems, where the mill feed would drop away for extended time periods due to blockages in the feed mechanism. Although the APC solution cannot avoid these disturbances, it does recover faster from these upsets than PID control could have done. The resulting decrease in mill load variance due to implementation of the APC solution was 5.5%.
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Mill load optimisation: The aim of the mill load optimiser is to make sure that the mill operates close to the apex of the power-load curve, which will result in more efficient milling (Smith, et al., 2004). Scatter plots of power-load curve estimates with and without the APC solution are shown in Figure 10. In these plots, a smoothed representation of the scatter plot is used to emphasise the point distribution densities. Comparing the two plots, the area of operation under influence of APC is more localised and close to the apex of the power-load curve than is the case when running the mill using PID control. The improved milling efficiency and energy efficiency are summarised in Table 1. The feed throughput increased 5.5% after implementation of the APC solution. The power usage per ton of feed throughput decreased nearly 1.8%, which has a significant influence on the overall operating costs for the plant, since energy is the highest contributor to the costs. Both of these results were calculated based on the downstream thickener flow rate, which is a more accurate indication of throughput increase than the mill feed rate, where even greater increases in throughput and energy efficiency were shown.
<table>
<thead>
<tr>
<th>APC</th>
<th>Performance Metric</th>
<th>Improvement %</th>
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<tr>
<td>Mill load optimisation (based on mill feed)</td>
<td>Reduction in power usage per ton of feed Increase in feed throughput</td>
<td>9.5 15</td>
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<tr>
<td>Mill load optimisation (based on thickener flow)</td>
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<tr>
<td>Cyclone feed sump</td>
<td>Increase in average flow to cyclone Reduction in variance of density in cyclone feed</td>
<td>11 13</td>
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Table 1 Performance comparison before and after advanced process control solution implementation.

In-mill density controller: Prior to implementation of the APC solution, in-mill density was controlled manually by operators based on manual samples taken periodically during a shift. Unfortunately, there is no electronic record of the data. As a result, in-mill density control performance cannot be compared for the purposes of the before-and-after analysis. Improved in-mill density control will, however, directly influence grinding efficiency. The improvement in grinding efficiency and energy efficiency noted above correlates with an improved control performance of the in-mill density.

The control performance will be highly dependent upon the accuracy of the in-mill density soft sensor used to estimate the in-mill density in between manual samples. The correlation between manual in-mill density samples and the estimated values is 70%. Therefore, to a first approximation, the density estimator reasonably predicts the linear dynamics of the in-mill density, allowing for real-time in-mill density control.

Sump density and cyclone feed flow control: The aim of the advanced sump controller is to stabilise the flow of the cyclone feed. Specifically, a cyclone feed with stable density and flow-rate properties results in a consistent and better separation within the cyclone. Figure 11 shows the density distribution of the sump content prior to and after implementation of the APC solution. The APC solution achieved significantly better density control around the desired set point. As summarised in Table 1, the variation in the sump density (which feeds to the cyclone) decreased 13% after APC implementation. During the period of analysis, operational issues with the pump providing feed from the sump to the cyclone resulted in significant equipment-induced variability in the feed flow to the cyclone, which also will negatively impact the density in the sump due to the strict level control inside the sump. Irrespective of these disturbances, the density control remained tight and accurate.

Figure 11 Estimates of the cyclone feed density distribution using PID control strategy (left) and APC strategy (right).
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As previously mentioned, the control strategy manipulates the set point for the flow to the cyclone in order to stabilise the density. When comparing the flow SP prior to and after implementation of the new control solution, and taking into account operational changes, the standard deviation evaluated using a moving window decreased from 46.5 m$^3$/h to 27.8 m$^3$/h. Moreover, the APC solution resulted in a more predictable flow SP than with only PID control, as can be seen in Figure 12. The average flow also increased by more than 10%. As noted earlier, operational issues with the actual pump delivering the feed flow to the cyclone resulted in significant variation in the actual flow when compared to the requested set point. It is expected that when these operational issues have been resolved, even more stable flow to the cyclone will be achieved.

![Figure 12](image)

**Figure 12** Time-series trends comparing cyclone flow set point variation before and after implementation of APC solution. Using a moving window to account for process target shifts, an average standard deviation value of 46.5 m$^3$/h was observed for the cyclone flow prior to APC implementation, compared to a value of 27.8 m$^3$/h after APC implementation.

**Conclusion**

A framework towards the integration of asset and process-health monitoring for increasing plant availability and process efficiency was discussed and demonstrated using plant data from a gold mining operation in South Africa. The concept involves equipment monitoring, control-loop monitoring and process optimisation. Through leveraging predictive analytics and diagnostics, integrated asset and process-health monitoring can deliver throughput and plant availability.

For the case study discussed, early identification of sensor malfunctioning, as well as excessive lube oil flow, potentially prevented unplanned downtime that could have occurred from equipment and process degradation. Using advanced-control solutions on the investigated gold-beneficiation operation, a number of benefits were highlighted, including 5.5% reduction in mill load variance, 5.5% increase in feed throughput, 1.8% improvement in energy efficiency, as well as improved process stability. These improvements are particularly significant for gold operations, where maximising recovery and plant throughput is becoming a strategic imperative in the face of declining good quality ore reserves.
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References


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