# Challenges and successes at the Nkomati Nickel JV: pit-to product process improvements

by G. Cockburn*


## Synopsis

Nkomati Nickel JV exploits the ores of the Uitkomst Complex near Machadodorp in the Waterval Boven district in South Africa's Mpumalanga Province.

Due to factors such as the remote location, stellar growth in production, opencast mining methods, and ore characteristics, a number of innovative processing options were selected.

Nkomati has undertaken numerous initiatives over the last few years to improve plant running times, metallurgical performance, and operational profitability. Great emphasis has been placed on effectiveness of management control systems. A number of initiatives such as short interval control and time–in-state metrics have been implemented. A focus on improvement on availability and asset utilization of key items of equipment has been particularly effective.

While the ores are remarkably similar to the Merensky and UG2 reefs, the relatively high base metal sulphide content and mineralogical characteristics make metallurgical treatment somewhat different to the ores of the Bushveld Complex. The low head grades and flotation kinetics distinguish Nkomati from other base metal operations. Numerous milling and flotation optimization initiatives have resulted in dramatic improvements in throughput, recoveries, and concentrate grades.

This paper discusses the metallurgical, operational, and management challenges and the outcomes obtained.



**Keywords**

Uitkomst, Nkomati Nickel, sulphide mineralization, grade control, ore fragmentation, problem solving methodologies.


## Introduction

Nkomati Nickel JV has experienced a phenomenal growth rate over the last few years, from a 10 kt/month operation in 2006 to a 700 kt/month complex in 2013. This growth required the re-engineering of virtually every aspect of the operation, from mining new ore types with new methods, ore preparation and processing, to tailings deposition.

Many alternative processing methods were considered before the current flow sheets were adopted. Production of separate nickel and copper concentrates through successive selective flotation, Activox® leaching of concentrates, and local smelting of concentrates were assessed among other options. Ultimately, economic factors resulted in the current circuit choices. This expansion occurred against the backdrop of the ongoing global economic crisis, with persistent low metal prices.

This paper discusses many of the efforts that contributed the turnaround of Nkomati Nickel. Emphasis is placed on the challenges and successes at the MMZ plant, though the PCMZ plant showed similar improvements.

## The Uitkomst deposit

Nkomati Nickel JV exploits the Uitkomst deposit in South Africa's Mpumalanga province, in the mountains between Waterval Boven, Machadodorp, and Badplaas (Figure 1).

The orebody is an early-age (2044 Ma) Bushveld layered lenticular mafic-ultramafic intrusion into the basal sediments of the Transvaal Supergroup, approximately 9 km long and 1500 m wide (Figure 2). The deposit dips north-east at about 4 degrees. The deposit was exploited by AngloVaal with various partners since the early 1990s. Nkomati Nickel JV is a 50/50 partnership between African Rainbow Minerals and Norilsk Nickel Africa.

The orebody has multiple zones of sulphide mineralization:

- MSB: Massive Sulphide Body with Ni grades in excess of 2%. Mined since 1997, now mined out
- MMZ: Main Mineralized Zone. Head grades 0.3–0.7% Ni, approximately 0.37 % Ni average
- PCMZ: Peridotitic, Chromititic Mineralized Zone. Chrome-rich ore with grades of 0.2–1% Ni, 0.23% Ni average, chrome grades of 10-15% $Cr_2O_3$.
- Massive chromitite (often called PCR): stockpiled for a separate chrome washing plant, currently mothballed
- Basal Mineralized Zone: unexploited at present.

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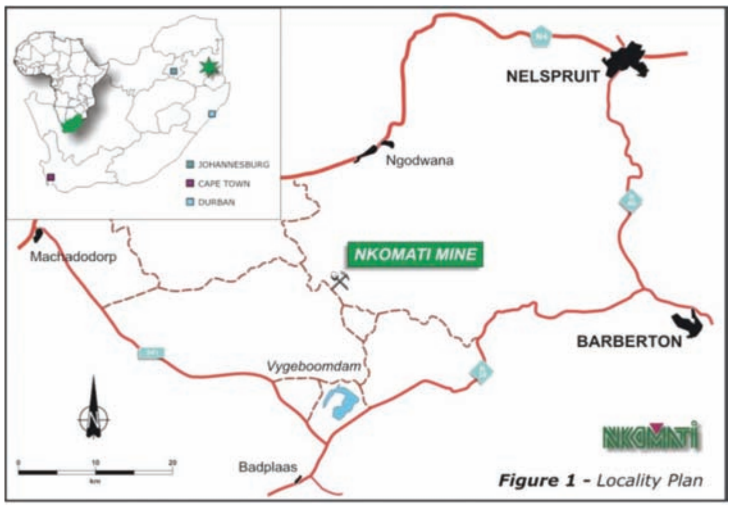



Figure 1—Location of Nkomati Nickel JV

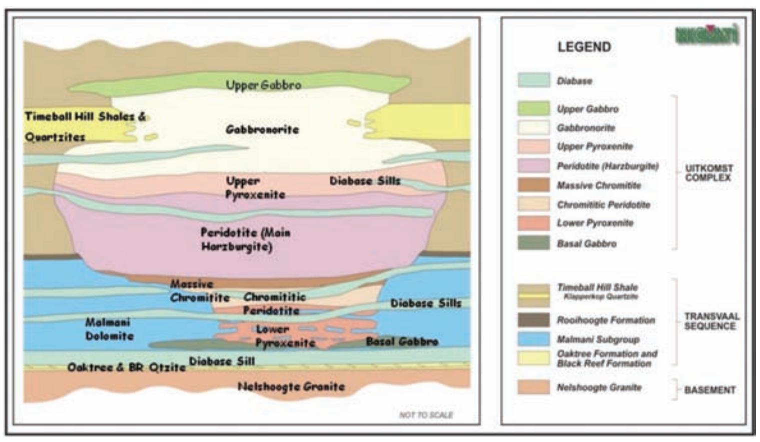



Figure 2—Idealized cross-section of Uitkomst deposit

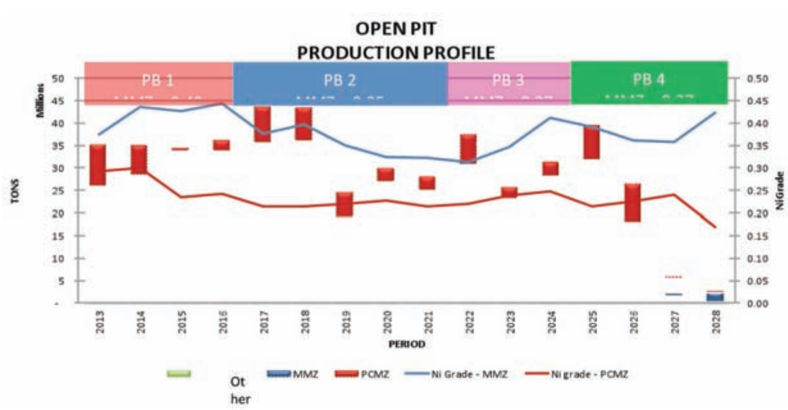



Figure 3—Life-of-mine ore production profile

## Ore production

Currently only the MMZ and PCMZ ores are mined. Ore production from the open pit is approximately 650 kt/month, of which approximately 300 kt is PCMZ and 350 kt MMZ. The MMZ is also mined in the underground mining section, producing approximately 50 kt per month by bord and pillar and longhole open stoping methods.

It must be noted that the production profile (Figure 3) is routinely optimized and updated as models are tuned and improved based on the outcomes of the RC drilling programme discussed below.

## Mineralogy

The pyroxenites and peridotites of the Lower Pyroxenite that hosts the MMZ consist mainly of clinopyroxene, olivine, and plagioclase. Hydrothermal action has resulted in extensive alteration of these minerals to amphibole, serpentine, biotite, and talc. Contamination of the ultramafic suite by country rocks accounts for the most of the calcite, dolomite, quartz, and plagioclase. Talc content is highly variable within the deposit and irregular (Brits, 2008)

Highly altered talc-rich zones are often associated with pyrite-rich zones, and the high flotation kinetics of both these minerals complicates the flotation process, resulting in lower pentlandite recoveries, dilution of the concentrate with pyrite, and reduced concentrate quality due to higher MgO levels.

Nickel is mainly contained within pentlandite, although a significant proportion (as much as 15%) occurs in solid solution within pyrrhotite and 1–2% within chlorite. Copper occurs almost exclusively as chalcopyrite, with some occurring as bornite (1–2%).

The MMZ in many ways resembles Merensky Reef, although it contains substantially lower platinum group metals (PGMs) and higher base metal sulphides (typically 5–8%) with traces of PGMs (1 g/t head grade, predominantly Merenskyite). The PCMZ resembles the UG2 Reef, with chrome grades of 7–15% $Cr_2O_3$. From the geologist's perspective, the ores are effectively the same with the exception of the chrome grades. The boundaries of the two ore types are not clearly delineated, making segregation of ore and prevention of cross-contamination challenging.

From a processing perspective, however, the ores are significantly different. The target liberation grind for MMZ ore is 67% -75 μm, although recoveries are relatively insensitive to grind. PCMZ ore is extremely sensitive to grind, with a target grind of 80% -75 μm, and drastic losses in recovery occur at lower grind values. Misplaced ore thus directly affects plant performance.

## Grade control

An extensive reverse circulation (RC) drilling programme at an initial hole spacing of 25 m × 25 m, and subsequently at 12 m × 12 m, has greatly enhanced the ability to model the orebody and so allow far better head grade control.

This is critical, considering the variability of grades within the orebody, and the fact that a substantial amount of PCMZ ore in particular is below economically viable grade. Management of the resource is thus a vital aspect of maximizing the value of the mine. RC drilling data and the resource models derived from it are extensively used in mine-to-mill reconciliations as well.

## Processing challenges

### *Primary gyratory crusher*

With the open pit supplying the vast bulk of the ore, a primary gyratory crusher at the pit was selected with overland conveyors to transport to the two plants. Loading and crushing are alternated between the two ore types, with crushed ore transported by conveyors approximately 3 km to the respective conical stockpiles located at the plants.

The Metso 54 × 75 Mk2 gyratory crusher was initially viewed as something of an Achilles' heel of the operation. The crusher suffered numerous breakdowns and trips and became the major process bottleneck. Although designed with an F80 of 450 mm and an F 100 of 1000 mm and a feed rate of 1600–1800 t/h, rocks substantially larger than design were routinely crushed, resulting in trips and mechanical failures. Tramp steel was also a major contributor to downtime.

Great focus was placed on preventing large rocks from entering the crusher. A 'SPLIT' camera and image analysis systems were introduced to monitor and record the size of rocks on trucks prior to tipping, with an additional system monitoring rock size during tipping. These systems provide a vital service in monitoring crusher feed PSD (Figure 4). Large rocks are prevented from entering the crusher largely through visual observation by control room operators, who reject truckloads with large rocks.

Interestingly, analysis of data indicated that high-amperage trips (and damage) on the crusher were not caused by large rocks alone. Correlation of SPLIT rock size images, vibration, and ampere readings indicated that smaller football-sized rocks, mostly from re-broken boulders fed to the crusher in the absence of fines, were as much of a challenge as very large rocks. This was exacerbated by wear on the liners, where the crusher cavity would wear to a 'hockey stick' shape, trapping critical-sized rocks, akin to bearings in a race.

Key to improving throughput and availability was the implementation of strict planned maintenance systems. Key performance indicators such as overall equipment efficiency (OEE) were introduced and proved very effective in monitoring the actual crusher performance. OEE is calculated from actual tons processed divided by the theoretical maximum the equipment can process over the period of consideration. This measure cuts out all the clutter and confusion of allocation of downtime, and provides a 'bottom line' performance value.

The overland conveyor system capacity was increased to accommodate the increase in crushed tonnages from 1300 to 2000 t/h. This necessitated the installation of larger head pulleys, shallower troughing angles on belts, and faster belt speeds to reduce persistent belt splice failures. Attention to best practices in splicing the steel-cored belts was vital to increase availability.

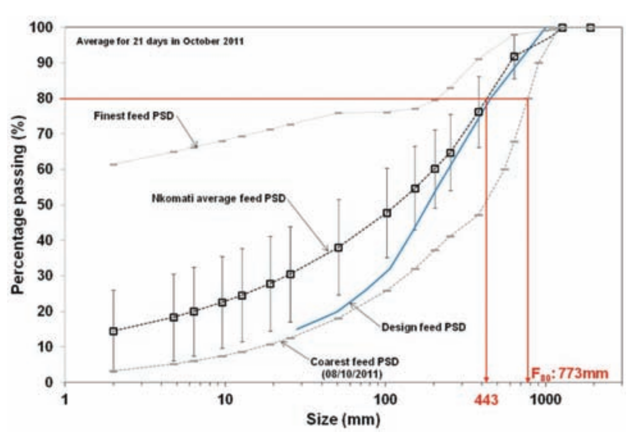



Figure 4—PSD analysis of crusher feed using the SPLIT camera system

Figure 5 clearly indicates the step change in total monthly milled tons for the complex, subsequent to the resolution of throughput constrains around the primary crusher in July/August 2012.

### *Ore fragmentation*

Fragmentation pattern improvements within the pit were realized through redesigned drilling patterns, and changes to the blast timing and blast direction. Interestingly, improved fragmentation was achieved at an increased hole spacing and much reduced powder factor. Production hole spacing was increased from 3.0 m × 3.5 m to 3.5 m × 3.5 m, while maintaining the 10.7 m hole depth and 3 m stemming material depth. Powder factor was reduced from 1.9 kg/m$^2$ to 1.4 kg/m$^2$.

Analysis of blasted material indicated that the majority of large rocks originated from the collar, close to the surface. The introduction of 3 m stab holes (with a relatively light charge) between production holes resolved this problem.

Fragmentation was further improved through changing the direction of the blast from north to south (up-dip) to west to east (cross-dip) and introducing substantially slower blast timing. The introduction of hole depth counters to ensure consistent hole depths as well as rigorous quality assurance inspections contributed to consistency in fragmentation as well as increased production.

### *MMZ comminution circuit*

The MMZ circuit design (Figure 6) employs a FAG primary mill in closed circuit with a vibrating screen and pebble crushers. A secondary ball mill in closed circuit with cyclones supplies feed to the float circuit at SG 1.3–1.34, 70% -75 μm at 620 t/h. Design considerations and alternative comminution options considered were discussed by Wolmarans and Morgan (2009).

The choice of this circuit caused extensive debate, as the FAG mill was viewed by some as a 'stone washer', that would result in excessive metal losses through the sliming of softer nickel minerals. The proponents advocated that the reduced operating cost far outweighed potential recovery losses.

This circuit is very sensitive to feed particle size distribution as well as ore hardness. Excessive fine material (and coarse material) results in overloading of the mill. Maintaining a full stockpile of 20–30 kt live capacity contributes greatly to mill stability through consistent feed.

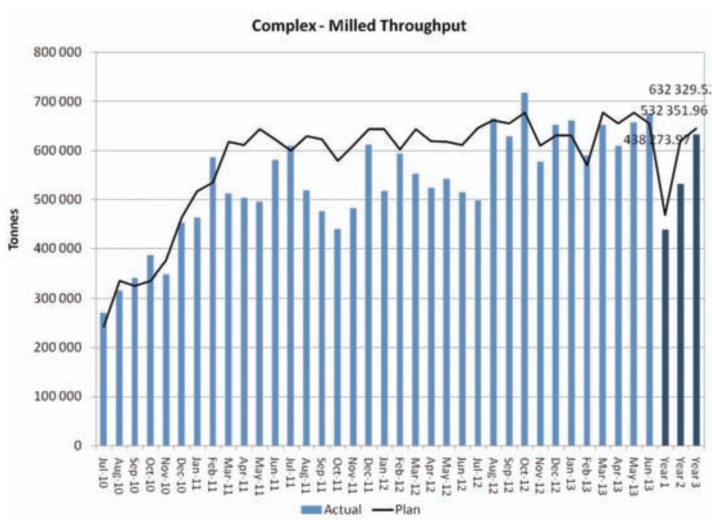



Figure 5—Metallurgical complex milled throughput

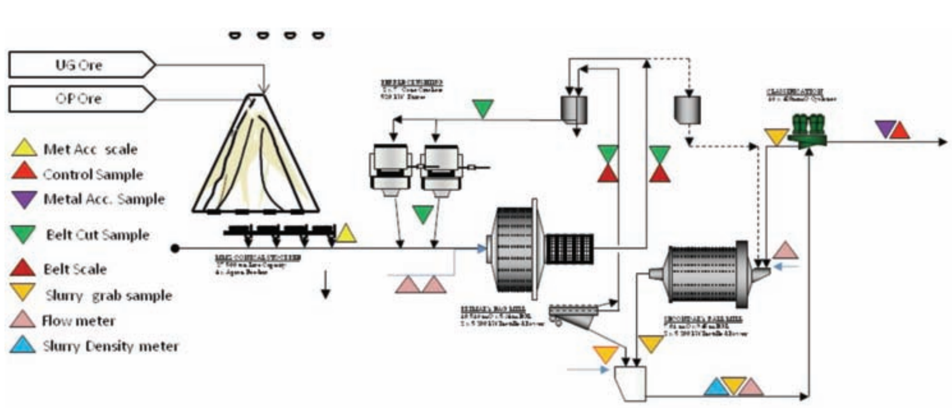



Figure 6—MMZ milling circuit flow sheet with sampling and monitoring points

Various regimes of feeder operation have been attempted to supply consistent PSD material to the mill, with operation of one inner and one outer feeder generally used. On-line image analysis of mill feed to determine PSD, with automated feeder selection, has been less successful. Segregation patterns vary as the stockpile is loaded or depleted, and prediction of individual feeder PSD has not yet been successful.

### MMZ FAG circuit pebble crushers

Optimization of the MMZ milling circuit highlighted the critical importance of the gap setting of the pebble crushers. While the process design criteria specified a closed side setting of 10–13 mm, realistically 19–21 mm was the best that could be achieved without causing frequent mechanical failures to the crushers.

Bypassing the pebble crushers or running with excessive gap setting would increase milling power from 24 to 30 kwh/t, with the mill feed rate cut back from 600 t/h to approximately 450 t/h due to overloading of the primary mill with pebbles. In addition, recoveries are affected by as much as 5–10%. While crusher comminution energy contributes just 400 kW to an average total of 16 MW for the FAG/ball mill/pebble crusher circuit (less than 2.5%), the pebble crusher is vital in removing critical-sized material from the circuit.

Extensive re-engineering of the crusher bushes and rigorous attention to planned maintenance, which was contracted to the OEM, allowed the crusher gap to be reduced gradually to 13 mm. The correct running in of the liners over a 4-week period was vital to prevent metal-on-metal contact and bush damage. Redesigned liners that do not need the extended running-in period are under development and are expected shortly.

A direct result of the higher-than-design crusher gap setting was an increased pebble crusher throughput, which exceeded the pebble production rate from the FAG mill. This resulted in stop/start operation of the crushers that threw ripples through the primary mill, mill discharge sump, and the cyclone circuits. Cyclical changes in froth stability were regularly observed in flotation, and were attributed to shifting grind as the milling circuit flows changed.

Data analysis indicated that stop/start operation of the crusher increases milling circuit power requirements by approximately 1 kWh/t, or R2.5 million per year at current power costs. Lost recovery costs are substantially higher (Van der Merwe, 2013).

Solving the crusher circuit instability was thus essential. Various initiatives were tested to balance crusher rate feed with capacity. Although manipulating the screen panel size on the primary mill discharge was effective, knock-on effects on secondary mill performance resulted in less than optimum secondary mill performance.

A novel approach was to increase the crusher speed by approximately 15%. While it may sound counter-intuitive to increase a crusher speed to reduce capacity, this encourages choke conditions and reduced throughput, although the exact change in capacity has yet to be quantified. Further refinements have been to re-set pebble bin low and high levels to encourage more frequent (but shorter) stops and starts. Downstream surge bins and other options are currently under consideration.

### Milling circuit expert system tuning

Tuning of the PxP mill expert control system and other control loops has assisted in improving stability. Assistance from the OEM, FL Smidth, was essential in understanding and optimizing the mill circuit control system in particular. An important change in philosophy was the fixing of the number of operating cyclones and varying sump water addition, rather than allowing the control system to open and close cyclones to maintain constant pressure. The effects of varied density of the cyclone feed appears to be less disruptive than opening and closing cyclones.

### MMZ comminution circuit operating costs

While detailed modelling of the milling circuit is yet to be done, indications are that milling efficiency on the FAG/ball mill circuit is close to what would be expected in a crushing and ball milling circuit. Comminution circuit operating costs are lower on the MMZ plant than the PCMZ plant (which utilizes conventional crushing and two stages of ball milling) by approximately R10 per ton. MMZ plant recoveries are close to or in excess of design figures. The selection of this circuit design over others considered by DRA appears to have been justified.

### MMZ flotation circuit

The MMZ flotation circuit (Figure 7) is a relatively standard rougher-cleaner-recleaner configuration. A combined nickel-copper-cobalt and PGM concentrate is collected from the recleaner. Currently the pyrrhotite scavengers function as extended rougher capacity.

One of the immense challenges on the flotation circuit has been to achieve operational stability, and the resolution of a number of issues has contributed to the current relatively smooth operation.

### Flotation cell level control

Analysis of the cumulative level control valve outputs of the cells in the two parallel rougher banks indicated that the one bank received more flow than the other. In addition, the cell discharge valves would saturate at 100% output more regularly on the one bank, resulting in excessive rougher concentrate volumetric flow to the cleaner circuit. The unequal flow split was attributed to an inherent flaw in the design of the splitter between the two banks.

Excellent results were obtained with the implementation of the Gipronickel mass pull control algorithm. This relatively simple loop adjusts air to the flotation bank based on volumetric flow of concentrate. Although not as advanced as some concentrate mass pull control models, this system has been very effective in breaking the cyclical swings in recirculating load that characterized the circuit.

Flotation cell level control issues were exacerbated by the piping arrangement of the tailings from the rougher and scavenger banks. The gooseneck discharge pipes collect grit unable to be carried over with the tailings. Insufficient head on the gravity flow arrangement to the tailings thickener restricts further easy solutions, and alternative solutions are being considered.

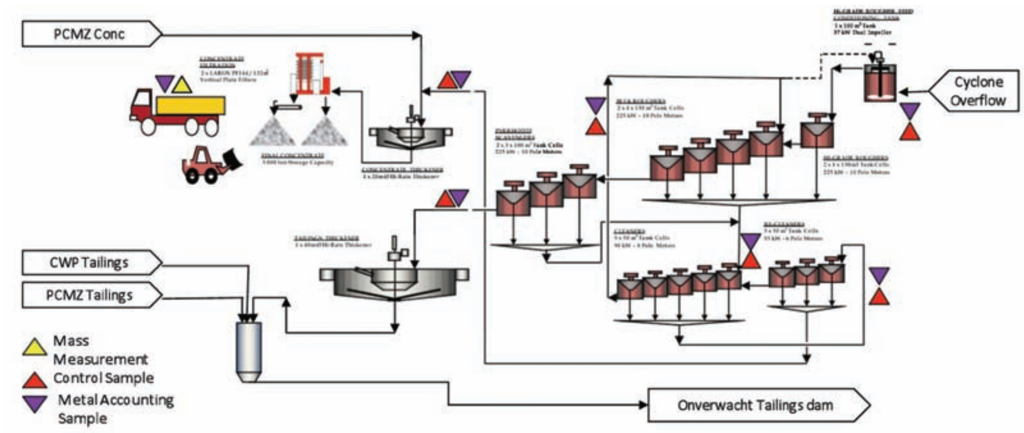



Figure 7—MMZ flotation circuit flow diagram

#### *Reagent optimization*

Talc and serpentine are the main contributors to high MgO levels in the concentrate, which incur severe smelter treatment penalties. Both these minerals have fast flotation kinetics and a strong froth stabilizing action. Under-depression results in vastly increased mass pulls, increased circulating loads, and low concentrate grades while also resulting in recovery losses.

Extensive tuning of the flotation circuit reagents has improved concentrate grades dramatically. Depressant allocation within the circuit has largely been shifted to the cleaners and re-cleaners. Careful control of collector has limited the over-collection of gangue.

The main value minerals recovered from the MMZ ore are pentlandite and chalcopyrite, while substantial (and variable) amounts of pyrite and pyrrhotite occur. Pyrite and chalcopyrite have substantially higher flotation kinetics than pentlandite, and mass pull control during periods of abnormal ore conditions is critical in maintaining recoveries.

#### *Operator training*

It is an easy mistake for inexperienced operators to produce, for example, a high-grade pyrite concentrate at the expense of nickel recovery. While many operators had extensive exposure to PGM flotation, fewer had base metal flotation experience. Training of operators, control room operators, and metallurgists has paid off very well in terms of reducing and largely eliminating poor plant performance due to misdiagnosis or incorrect response to operational upset conditions. In combination with the 'process recipes' discussed below, operation of the MMZ plant has vastly improved.

#### *Plant operational management*

##### *Process recipes*

Of all the improvements implemented at the MMZ plant, the introduction of 'process recipes' has to rank among the most successful in ensuring consistent operation.

Process recipes stipulate the ranges within which key process variable must be run. These include froth depths, air addition rates, mill power draw, cyclone feed pressures, and SGs and other metallurgical variables. These have added immensely to the stability of the operation of the plant, and have prevented operator-induced instability due to incorrect or excessive corrections of perceived process upsets. Process recipes are adjusted infrequently, and only in consultation with senior management, metallurgists, and production staff and are signed off at senior level.

'Short-interval control' (SIC) was introduced as a way of guiding operators into checking the key process variables to assess the plant performance on a regular routine basis. This consists of a set of focused log sheets that required routine checks and monitoring, as well as monitoring of 2-hourly quality control assay results. These consist of a set of calculations attached to the 2-hourly quality control assay reporting sheets. Flotation circuit recoveries, upgrade ratios across flotation banks, ratios between Fe/MgO, Ni, and Fe, and other indicators of concentrate quality or ore quality warn operators of current of looming plant performance issues.

SIC is being extended with the introduction of time-in-state (TIS) monitoring. TIS presents the operator with a 'dial' dedicated to each section of the plant (Figure 8). Data analysis has been used to assess the key parameters that influence the performance of a specific section, as well at the whole plant. An algorithm monitors multiple contributing factors, such as froth depths, aeration rate, concentrate sump levels, and flotation cell feed and product grades

The operator is presented with and easy–to-read dial, with bar chart indicating what factor is out of range, and comments as to what 'lever' to pull to correct the situation. Essential to the deployment of the TIS system has been the development and implementation of valid models that underlie the 'idea state' index.

##### *Performance mapping*

Extensive analysis of data using 'performance mapping' is used. Historical data pertaining to key variables considered by plant operational and metallurgical staff to be the main drivers and indicators of ideal operating performance is analysed, and the correlations are plotted in 2-dimensional space.

These performance maps have been extremely useful in indicating the correlations between various operational variables and process performance. They also indicate how often the process is in various 'states', which are often not the 'ideal state'. The technique has been very useful in indicating appropriate process recipe set-points.

It is important to note that this method is used in conjunction with the plotting of trends and conventional metallurgical evaluation methods.

Graphics such as those shown in Figure 9 were generated for all major variables deemed to potentially impact plant performance, or to be indicators of conditions that would affect plant performance. The example shown correlates the rougher bank flotation performance with key parameters such as mill power, as well as other indicators such as the rougher motor power draw. While rougher cell power draw is not considered to be a key variable, it is an indicator of cell aeration, flotation feed densities, or wear on the flotation cell mechanism that requires scrutiny. These indicators are used together with the TIS dials to advise operators on what actions should be taken to rectify sub-optimum operating conditions.

### *Fluid Reports*

Fluid Reports is an automated reporting system developed by Blue Nickel in conjunction with U-Drive. This system draws data from the SCADA's historian, and generates automated reports and trends on the performance of key process variables, including feed tons, key flow rates, power consumption, or similar process variables that directly affect throughput, recoveries, or product quality (Figure 10).

While not containing any information not already available on the SCADA, the system has proved extremely useful in producing easy-to-read trends tailored to an audience who do not have ready access to SCADA viewers. An added benefit is the interpretation of trends relating to process control issues, inserted into the trends as 'sticky notes', and detailed in a separate report. Many of the metallurgical and control issues resolved were identified in Fluid Reports and resolved with the assistance of the Blue Nickel team.

A similar user-configurable web-based application allows real-time trends to be viewed from any computer or smartphone. These features are aimed at providing better

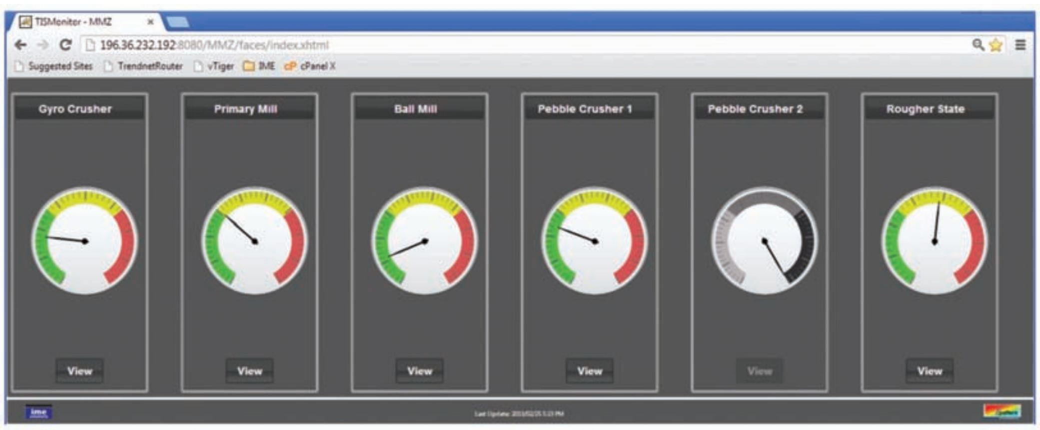



**Figure 8—Time-in-state performance indication dials**

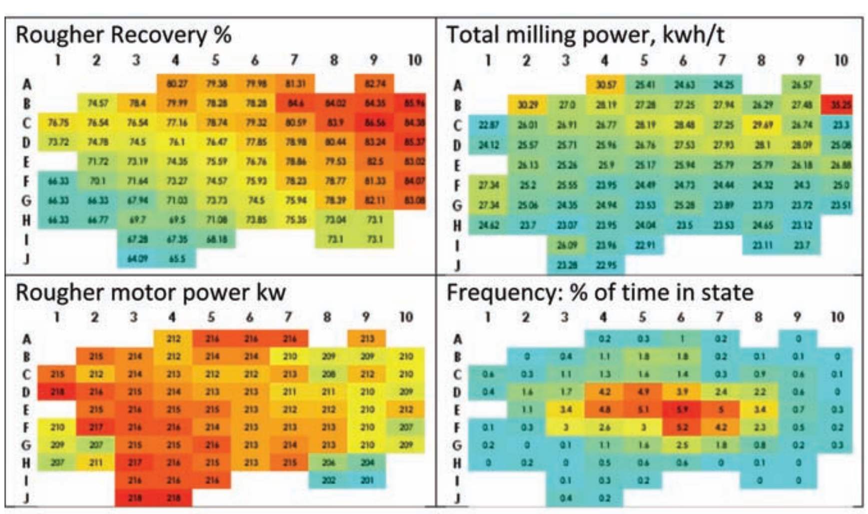



**Figure 9—Performance maps**

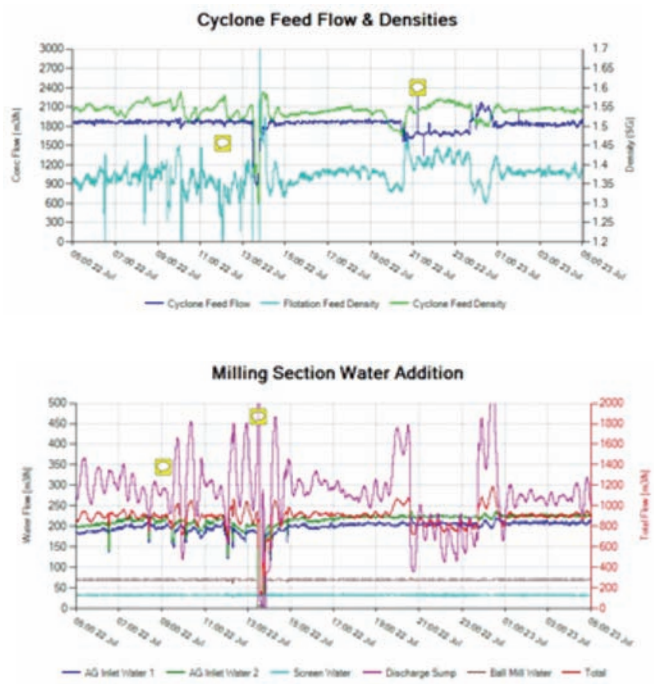



**Figure 10—Fluid Reports trend reporting**

support to operational staff outside office hours without the need for engineering, instrument, or metallurgical staff to be called out in the case of upset conditions.

### *Management systems*

Lastly, the benefits of strong focused leadership have to be recognized. Recent management changes, with fresh ideas and methods, have had a very positive influence on productivity.

Some of the most effective tools implemented were the 'Gap' list and '5 Why' problem-solving methodologies. These contributed to a halving of the monthly mill trip rate in one month, from approximately 60 to less than 30 trips. Current efforts are aimed at dropping this to below 10 trips per month.

The importance of housekeeping on morale and discipline cannot be understated. The mills are arguably the largest, most expensive, and most visible items on a plant.

The condition and maintenance standards on the mills (Figure 11) provide immediate visual reference on the housekeeping and maintenance standards set for the rest of the operation.

## Plant performance improvements

Numerous efforts were conducted simultaneously to resolve the metallurgical, operational, and management issues discussed above. Isolation of the contribution of individual process changes is thus difficult.

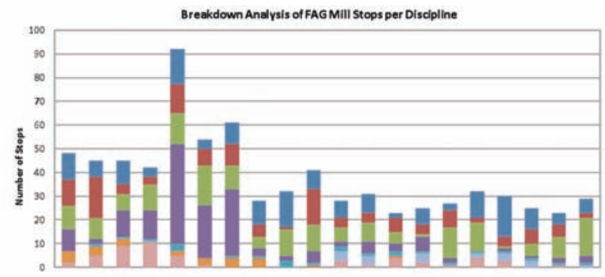
The impact of the introduction of new management techniques can probably best be seen in the reduction in mill trips. A step change in mill trips coincided with new management appointments in the middle of 2012 (Figure 12).

It can be seen that mill stoppages due to instrumentation issues persisted throughout the period ending June 2013. It must highlighted that this is not due to a failing of the management systems implemented, but rather the time taken to resolve systemic instrumentation issues.

Reduced mill breakdowns as well as the resolution of maintenance and process throughput issues at the primary crusher can largely be credited with the improved MMZ plant throughput, as can be seen in Figure 13. Step change improvements in milled tons can be seen from mid-July 2012.

Poor mill throughput in July 2012 was due to downtime attributed to pre-existing damage to FAG mill bearings and lube system. Throughput on the MMZ plant has exceeded nameplate tonnages regularly since, and is expected to do so more consistently on the conclusion of current improvement projects.

**Figure 11—Mills and lube rooms**




| | Nov-11 | Dec-11 | Jan-12 | Feb-12 | Mar-12 | Apr-12 | May-12 | Jun-12 | Jul-12 | Aug-12 | Sep-12 | Oct-12 | Nov-12 | Dec-12 | Jan-13 | Feb-13 | Mar-13 | Apr-13 | May-13 | Jun-13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mechanical | 11 | 7 | 10 | 4 | 15 | 4 | 9 | 10 | 15 | 8 | 7 | 8 | 2 | 7 | 3 | 11 | 17 | 9 | 5 | 6 |
| Electrical | 11 | 17 | 4 | 3 | 12 | 7 | 9 | 5 | 1 | 15 | 4 | 4 | 6 | 4 | 7 | 2 | 4 | 6 | 5 | 2 |
| Instrumentation | 10 | 9 | 7 | 11 | 13 | 17 | 10 | 5 | 11 | 11 | 6 | 8 | 5 | 1 | 13 | 12 | 1 | 5 | 9 | 16 |
| Operational | 9 | 2 | 11 | 12 | 42 | 22 | 28 | 3 | 2 | 5 | 2 | 5 | 3 | 6 | 2 | 0 | 1 | 1 | 2 | 3 |
| Planned Maintenance | 0 | 1 | 1 | 1 | 3 | 0 | 1 | 1 | 3 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Ore Shortage | 5 | 4 | 3 | 0 | 2 | 3 | 4 | 4 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Figure 12—MMZ mill breakdown analysis**

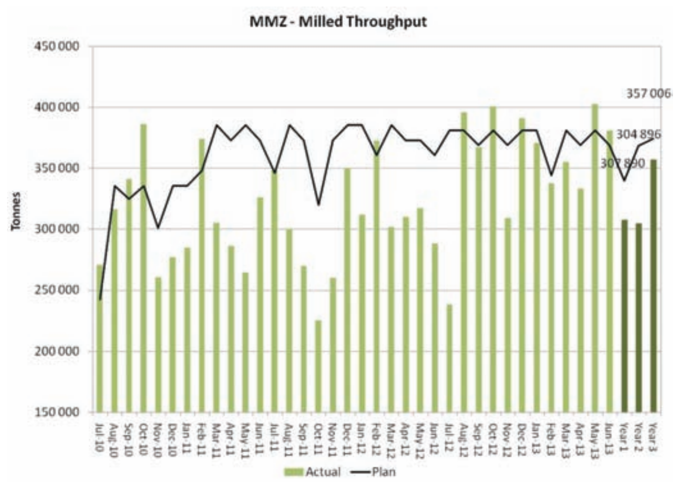



**Figure 13—MMZ plant thoughput**

The metallurgical impact of the efforts to improve milling circuit stability, as well resolve the issues concerning the pebble crushers, are difficult to isolate from the impact of efforts to optimize the flotation circuit control.

While step change improvements in throughput are apparent the case of crusher and milled tons, gradual improvements in recovery are apparent. Figure 14 shows monthly nickel recovery figures.

## Conclusions

Despite a number of challenges, the Nkomati Nickel JV has seen very strong growth in production over the last year.

A number of major equipment reliability and throughput issues at the mills and primary crusher were resolved, allowing for increased concentrate production. This has been achieved by optimization of the existing equipment, without major capital investment.

The successful introduction of problem-solving methodologies such Gap lists and 5 Whys played a significant role in identifying and addressing equipment and operational issues.

Close cooperation with OEMs was crucial in resolving the issues around both the Metso primary crusher and FLS pebble crushers.

Improved fragmentation was achieved at lower powder factors, allowing improved primary crusher capacity and less downtime on the primary crusher.

Improved mill throughput and more stable milling circuit operation were achieved, with increased milling energy efficiency, through resolution of maintenance and operational issues around the pebble crushers. The importance of achieving design operational set-points on key equipment such as pebble crushers in a FAG circuit is clear. The operating cost of the FAG mill is approximately R10 per ton cheaper than the conventional crushing and ball milling circuit of the PCMZ plant.

Numerous flotation circuit optimization projects, including the implementation of process recipes, Gipronickel mass pull control, IME's time-in-state monitoring, and performance mapping, as well as the use of Blue Nickel's Fluid Reports, have collectively contributed to recovery improvements of 13.1% year–on-year (62.3% in 2011/2012 to 75.4% in 2012/2013).

Production trends indicate that the improvements are sustainable and that the figures for the year ahead should surpass the previous year's performance.

This effort cannot be attributed to a single department, but is rather the culmination of the combined efforts of

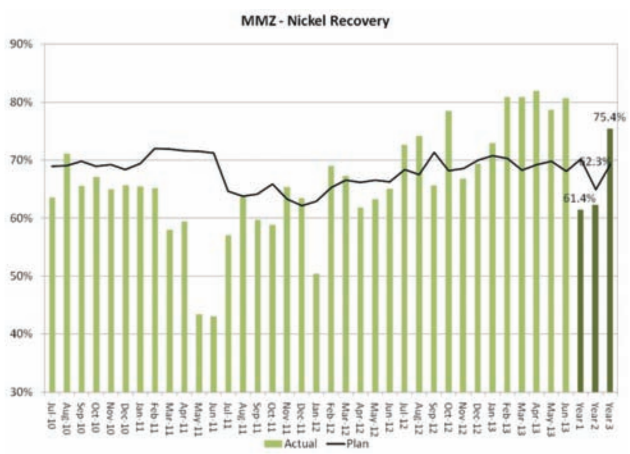



**Figure 14—MMZ plant nickel recovery**

mining, engineering, production, and metallurgy. The input of various consultants, including the development of analytical and information systems tools, has been invaluable, as has been that of the engineering consultants and head office advisors.

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