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# CURRENT TRENDS IN SAG AND AG MILL OPERABILITY AND CONTROL

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## ABSTRACT

With increased pressure for companies to cut costs during design of new mineral processing plants, overall plant design has changed over the last decade with less surge capacity installed and less design for feed blending. This has changed the dynamics and operability of new SAG and AG comminution circuits, where disturbances due to direct tipping of feed and recycle crusher operation have resulted in the evolution of control of SAG and AG mills to utilise new advanced control techniques. These techniques are necessary to maintain stability and optimise the performance of the new SAG and AG comminution circuits.
This paper describes advances in the operation and control of new SAG mill installations in Australia. The case studies show the difficulties in operability and control of grinding circuits where direct tipping and ore type variations, coarse ore feeder trips and low surge capacity in the recycle crushing circuit are present. The case studies also describe the benefits of applying the new control techniques in these applications for both open and closed circuit SAG comminution circuits.

## INTRODUCTION

In recent years, new mineral processing plants have been constructed and commissioned throughout the world. These new plants have been constructed and operated with tight budgets. Direct tipping of ore,



significant ore type variation, coarse ore feeder trips and the removal of surge bins from recycle crusher circuits has required new control techniques to stabilise the grinding circuit in these processing plants, specifically with SAG mills.

Manta Controls, an Australian based company has been engaged to optimise the various processing units on sites in Australia and Africa by improving the process control strategies.

This paper describes the improvements in both open and closed circuit SAG mill control on two sites in Australia that have adopted the new control technology developed by Manta Controls called the Manta Cube.

## OVERVIEW OF THE MANTA CUBE

Manta Controls has developed a control technology called the Manta Cube. This process control technology utilises a variety of fundamental control techniques, including the traditional expert system approach together with new techniques specifically developed by Manta Controls that ensure that the dynamic behaviour of the circuit is understood and utilised in the design of the Manta Cube, which is primarily made up of four parts,

1. The Cube – this determines the operating mode of the unit process such as a SAG mill
2. The Cube expert decision matrix – this describes what is required to get the SAG mill back to the required operating band.
3. The Cube engine – this is a fundamental control structure utilising multivariable and decoupling techniques.
4. The Cube optimisers – there are various optimisers developed to ensure that the system is optimising the control objective such as maximum throughput.

The primary advantages of the Cube Control system are,

1. The system is configured locally on the site's DCS or PLC system using the inbuilt functionality available on these systems. This eliminates the need to maintain new systems, learn a new programming platform and removes additional hardware points of failure. Any system developed using the Manta Cube maintains the robustness and integrity of the original site control system as it is developed without reliance on communication to third party computer processors.

2. The system utilises the dynamics of the process in the design of the control strategies, coupled with traditional expert system type approaches and new control techniques developed by Manta Controls, the overall system is very robust.
3. The underlying architecture of the Cube Engine is structured utilising a modular framework making maintenance and upgrades very easy.
4. The business objectives are defined in the strategy design of the Manta Cube and the optimising logic continuously drives to achieve these outcomes.

## INTEGRATION OF THE MANTA CUBE

The SAG Mill Cube system graphic shown in Figure 1 demonstrates that the system is fully integrated with the Yokogawa CS3000 DCS used at Newcrest Mining Telfer Operation and Figure 2 (next page) demonstrates that the system is fully integrated with the Allen Bradley ControlLogix System used at Goldfields St Ives. The system is also integrated with the Foxboro IA and Emersons Delta V control systems.

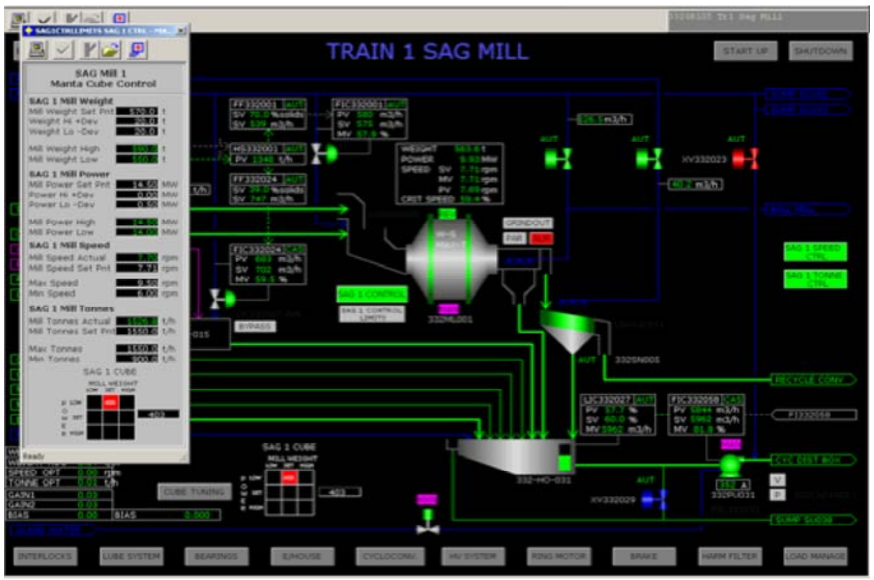


Figure 1. Newcrest Mining Telfer Operation SAG Mill Operator Graphic with the Manta Cube data entry pop up integrated on the Yokogawa CS3000 DCS.



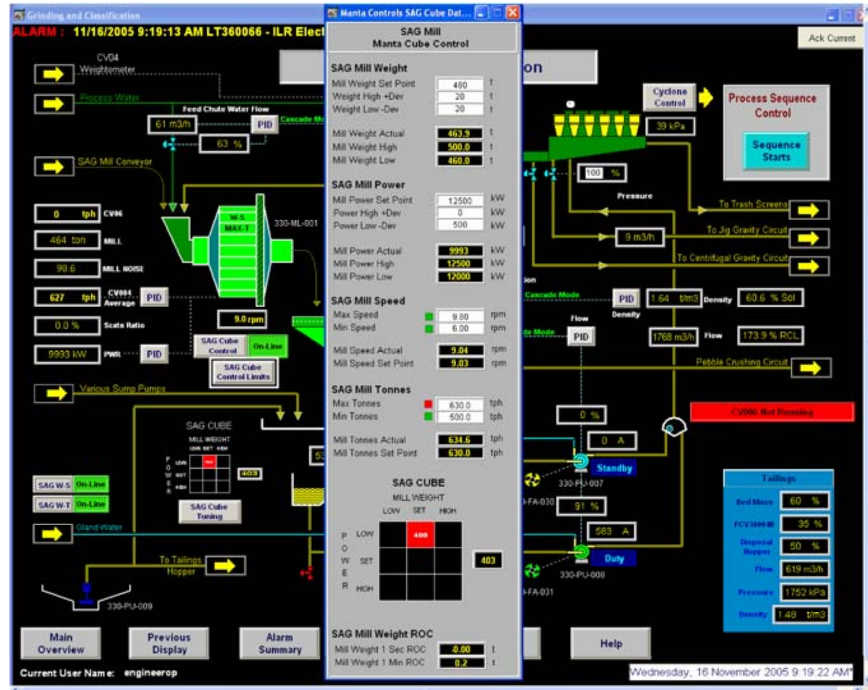


Figure 2. Manta Cube integrated on the Allen Bradley ControlLogix system at Goldfields St Ives.

## CASE STUDIES

The two sites that will be covered in this paper are,

1. Newcrest Mining Telfer Operations
2. Goldfields St Ives Lefroy Mill

A brief description of the grinding circuit is given for each site with the performance of the Manta Cube.

### Newcrest Mining Telfer Operation

**Open Circuit SAG Mills**

Newcrest Mining commissioned their new copper/gold plant at Telfer located in the Pilbara of Western Australia in November 2004. The Telfer project has two parallel grinding circuits, or trains. Each grinding train consists of a coarse ore feed system with three pairs of feeders, a pebble crusher, a 10.97m (36’) SAG mill and a 7.3m (24’) ball mill in closed circuit with 660mm (26”) Krebs hydrocyclones. A schematic of the Telfer grinding circuit is shown in Figure 3 (next page).

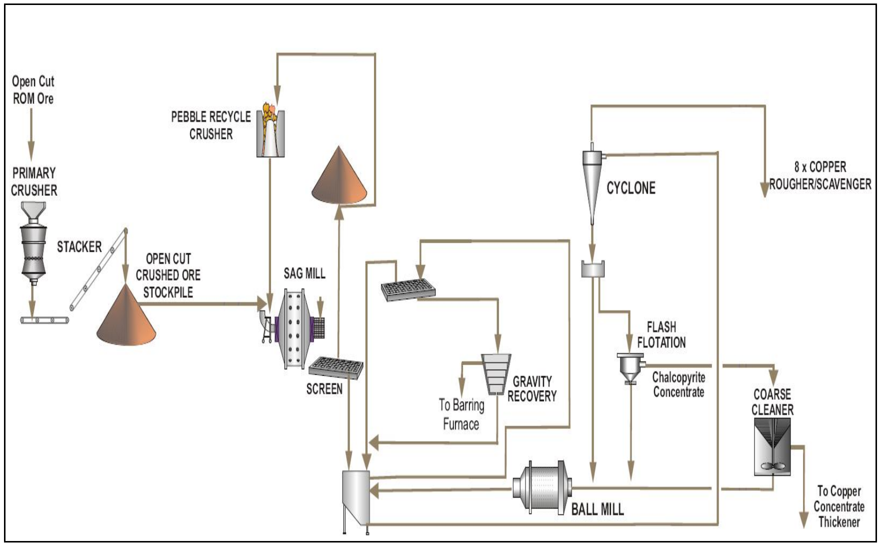


Figure 3. Schematic of the Newcrest Mining Telfer Operation grinding circuit.

The Telfer grinding circuit is very well designed and constructed with the ability to blend ore using radial stackers over the coarse ore stockpile. In normal operation the Telfer SAG mills are used in open circuit, however the design also provides the flexibility for closed circuit operation which is used from time to time.
Both SAG mills can also be operated at 0.01 rpm via the ABB wrap around motor control system. This is excellent for good SAG mill control.

There are three major sources of disturbances that produce instability in the grinding circuit. These are,

1. Coarse ore stock pile feeder trips
2. Large variability in ore competency in the mill feed
3. Recycle Crusher Operation

Controlling a SAG mill utilising older control techniques will give adequate control, however in order to provide control that will continuously optimise the grinding circuit coping with the above disturbances, new control techniques needed to be developed.

Manta Controls has developed a control system called the Manta Cube. This technology utilises new control techniques that can be implemented on Distributed Control Systems (DCS) and Programmable Logic Controllers (PLC) that utilise the IEC61131-6 control standard. There is no need to have separate operating systems linked to the plant control



system. Since the Manta Cube can operate on both DCS and PLC systems, the system integrity is the same as the plant control system.

With increasing pressure to lower operating costs, a practice that is also becoming more common is to direct tip feed to the primary crusher rather than creating blend fingers.

The Manta Cube is capable of detecting ore type changes on-line and compensating for this variation via manipulated variables such as mill speed, mill feed rate, feed density, feed size and other manipulated variables that are provided by the grinding circuit design.

**Manta Cube Performance at Newcrest Mining Telfer Operation**

The Coarse Ore Feed System

Figure 4 shows the effect on the feed rate system on one of the SAG mills at Telfer, prior to the Manta Cube feed control being implemented. A drop in feed is noticeable when one of the feeder pairs trip due to a fault condition. This drop in feed rate can cause problems with the mill weight decreasing for short periods of time. This has the potential to cause mechanical damage to the grate and lifters of the SAG mill.

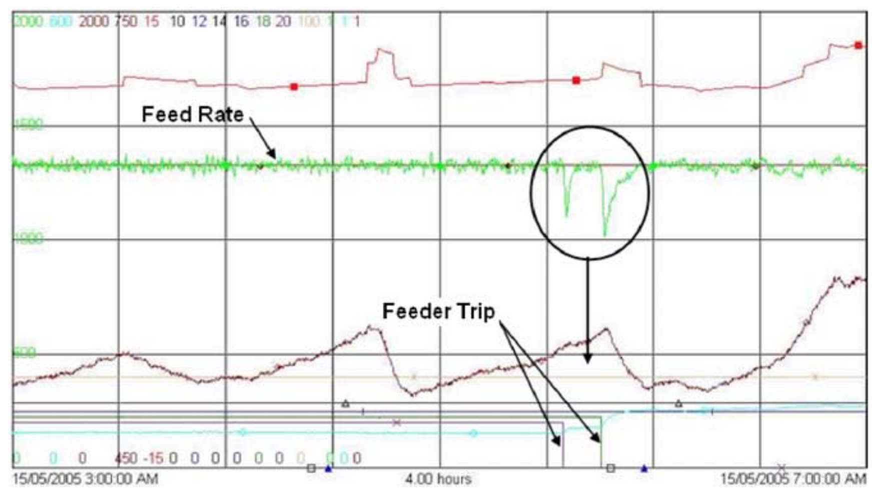


Figure 4. Effect of a feeder tripping on feed rate – before the Manta Cube.

With the installation of the Manta Cube feed controller, the drop in feed rate is virtually eliminated when a feeder trips. This is shown in Figure 5 on the next page. The feed controller is capable of distributing the lost feed of the tripped feeder to all other operational feeders in the space of

one scan thus eliminating a drop in the overall feed rate. This provides a very robust feed system that is capable of minimising mechanical damage of the mill grate and lifters due to a drop in mill weight when associated to a partial loss of feed to the SAG mill.

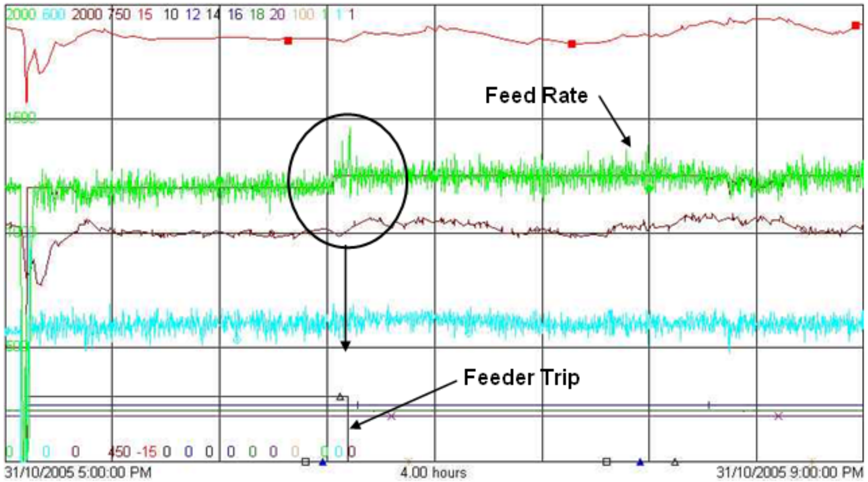


Figure 5. The effect of a feeder tripping on feed rate – with the Manta Cube.

The Effect Of Variable Ore Type

Telfer is a high tonnage, variable ore body which has both open pit and underground ore sources. The ore can vary in hardness from 8 BWi to 16 BWi.

The Manta Cube has been designed to detect for such ore type variations utilising fundamental control techniques. The Manta Cube speed system compensates by automatically changing the overall operating speed band of the SAG mill for the duration of the disturbance. This is a very robust and elegant system with the end result being stable SAG mill weight. Improvements in stability of the SAG mill weight can be seen when comparing Figure 10 and Figure 11.

The Effect Of The Recycle Crushing Circuit

Typical new designs of recycle crushing circuits have the scats by-passing directly onto the main feed conveyor rather than into a surge bin which does disturb the mill weight. Surge capacity is removed as it is no longer economic at high throughput rates and process control tools have become more sophisticated to cope with these changes. An example of the disturbance of the SAG mill weight due to the recycle crusher by-passed is shown in Figure 6 (next page).



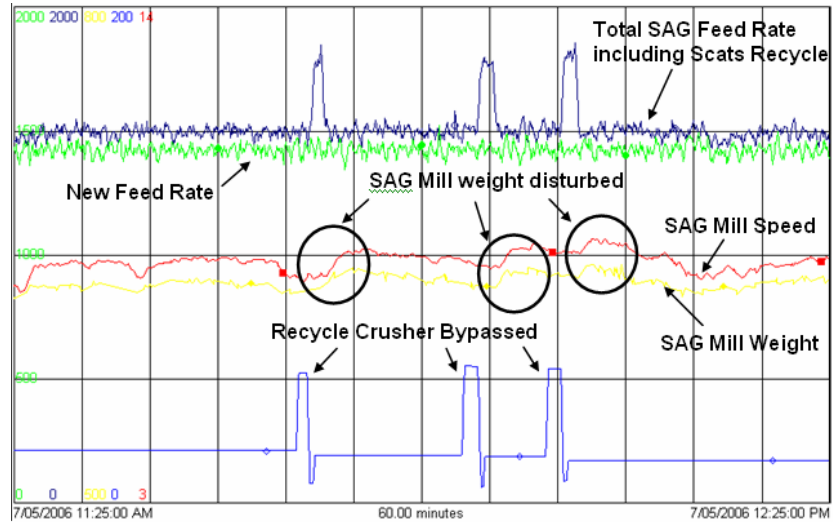


Figure 6. By-Passing of recycle crushing circuit before Manta Cube.

The Manta Cube can be configured to monitor for these cases and the system compensates by immediately changing the feed rate when in bypass. The net result is that the disturbance to the mill weight is decreased. This is shown in Figure 7.

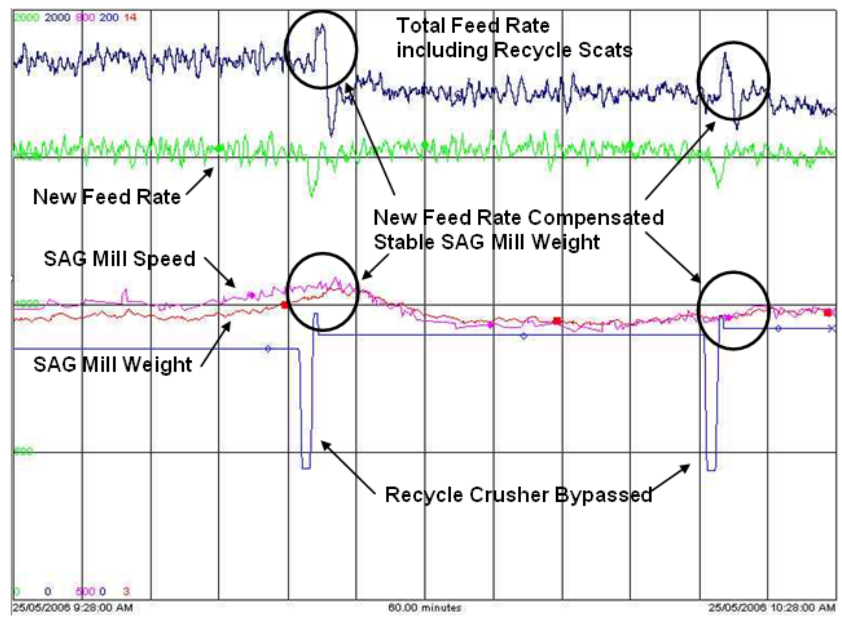


Figure 7. By-Passing of recycle crushing circuit with Manta Cube.

Other disturbances of the mill weight occur when feed to the recycle crusher is stopped and started. This is shown in Figure 8.

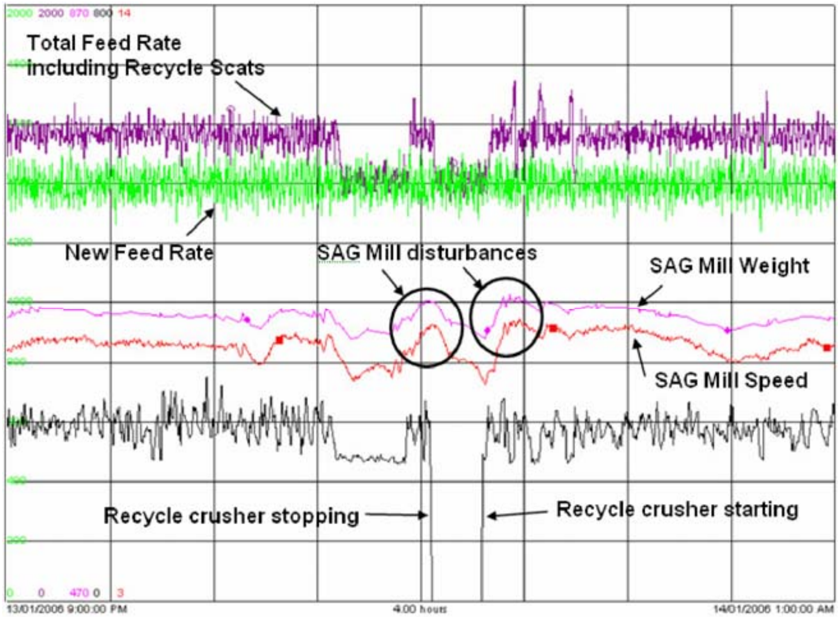


Figure 8. Stop and start recycle crushing circuit without the Manta Cube.

This condition is also monitored and the control system self compensates the new feed rate to minimise disturbances to the SAG mill weight. This is shown in Figure 9.

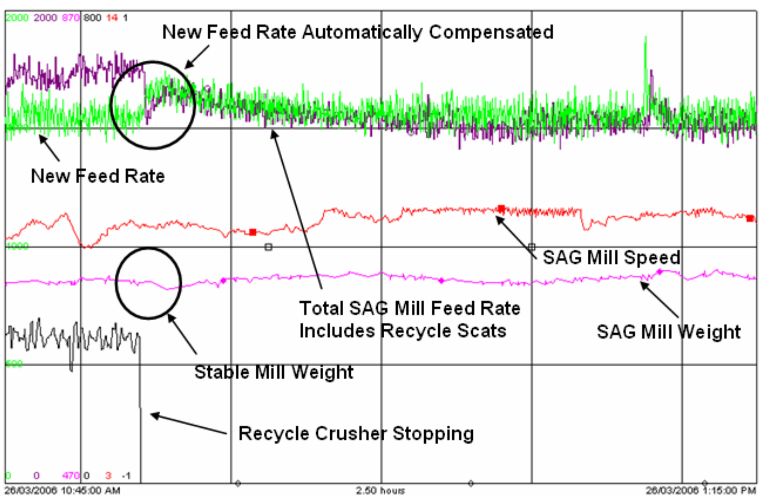


Figure 9. Stopping recycle crushing circuit with the Manta Cube.



The Telfer Train 1 SAG Mill

Operational data was collected for a six week prior to the installation of the Manta Cube. Four sets of SAG mill operational data are graphed as histograms in Figure 10. These are,

1. The SAG mill speed (rpm)
2. The SAG mill power (MW)
3. The SAG mill feed rate (tph)
4. The SAG mill weight (tonnes)

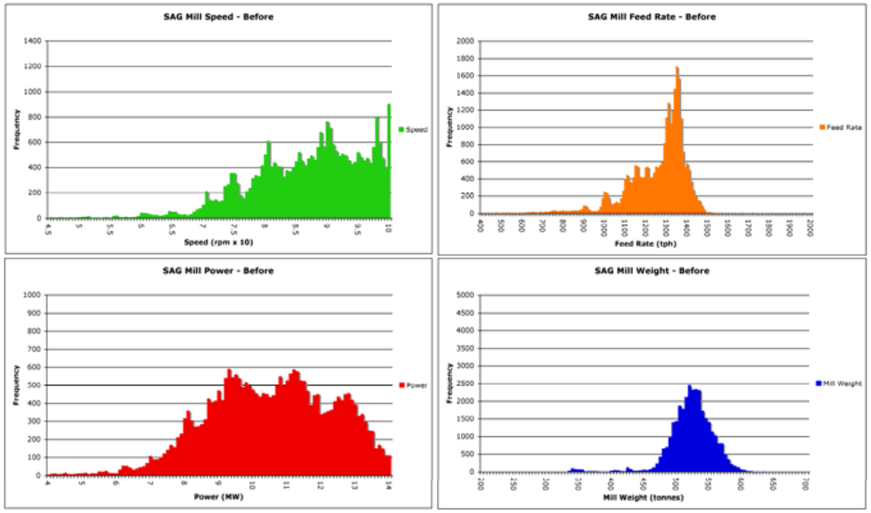


Figure 10. The performance of Train 1 SAG Mill - before the new Manta Cube.

It can be seen from this set of operational data that the mill weight varies over a wide range and this is consistent with normal operator control of a SAG mill.

The Manta Cube was then configured on both SAG mill trains at Telfer with operator training provided on each of the shifts. After a six week period of operation, mill performance data was again collected and displayed as histograms. This is shown in Figure 11 (next page) for SAG mill train 1. It is quite noticeable from Figure 11, that the mill weight is being tightly controlled around the required set point band. This was a key objective requested from Newcrest Mining.

The feed rate distribution identifies a bimodal distribution. This is indicative of the differing ore types being processed the SAG mill. The Manta Cube managed these ore type variations whilst maintaining tight

control of the mill weight. A similar but overlapping bimodal distribution is evident in the SAG mill speed in Manta Cube control. It can be seen that the speed is also controlled within a tighter range due to the constraint management algorithms.

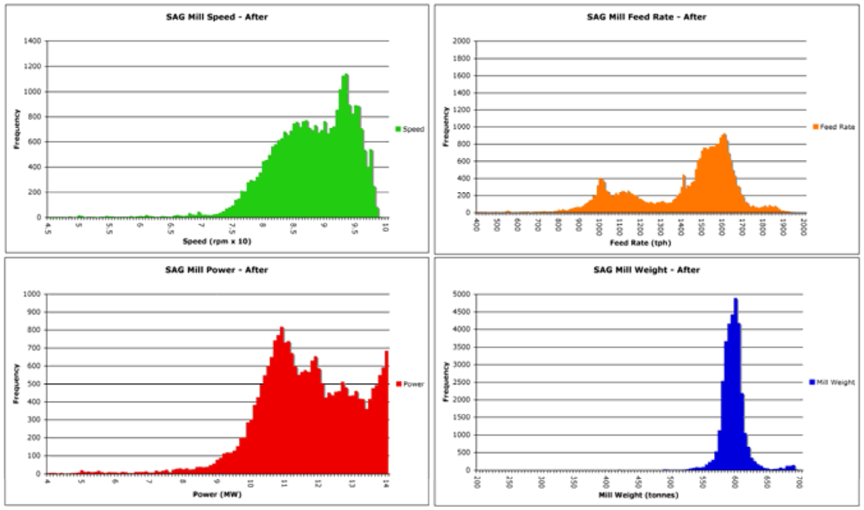


Figure 11. The performance of Train 1 SAG Mill - with the Manta Cube.

The SAG mill power distribution shows a shift to the right, indicating that the mill is being worked harder and using more of the available power draw. It can also be seen that the control system was working the mill harder by operating the mill at a higher speed range.

With the variability of the SAG mill weight reducing considerably, there will be benefits of improved stability in the downstream flotation circuit which was not quantified at the time of analysing the SAG mill performance data.

With the improved control of mill weight, the Manta Cube was able to increase the overall feed rate to the SAG mill as shown in the feed rate histogram of Figure 11. Due to production pressures, several improvements were being performed with the SAG mills at Telfer at one time. The increase of feed rate at the Telfer site was a combination of improved control and other parameters implemented by the Metallurgical group at Telfer. Since several projects were running in parallel, a percentage improvement simply due to the Manta Cube was difficult to quantify.



## Goldfields St Ives

### Closed Circuit SAG Mill

Goldfields commissioned their new gold plant located near Kambalda in Western Australia in December 2004. The St Ives grinding circuit consists of three coarse ore feeders and one soft ore feeder supplying a 10.97m (36') high aspect ratio single stage SAG mill in closed circuit with 508mm (20") Krebs hydrocyclones. The SAG mill is powered by an ABB variable speed 13 MW wraparound drive. The grinding circuit feeds directly to a leach circuit without the aid of a leach feed thickener. The grinding circuit also has a recycle scats crusher without any surge capacity when the recycle crusher is bypassed. A schematic of the St Ives grinding circuit is shown in Figure 12.

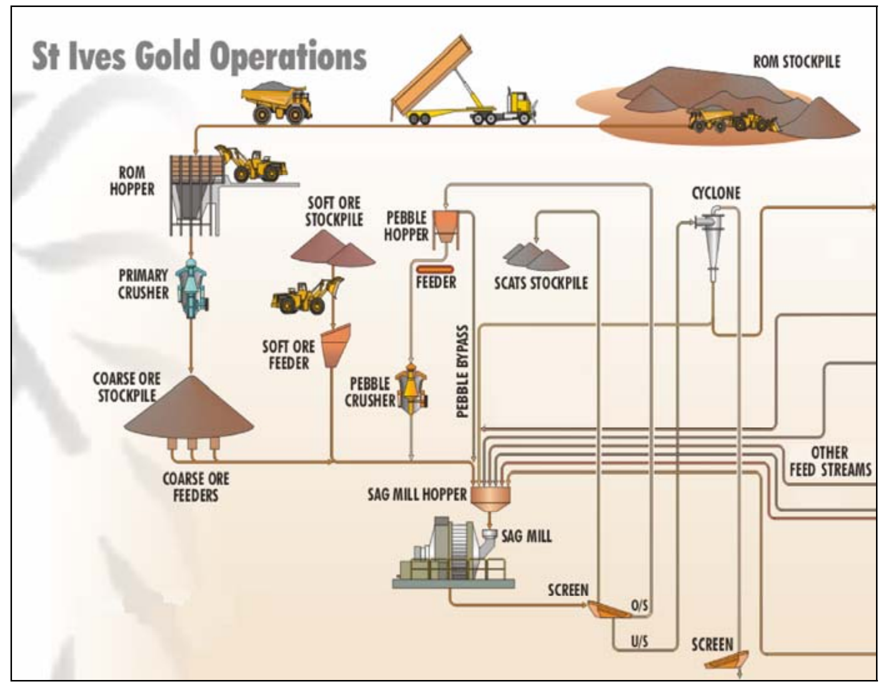


Figure 12. Schematic of the Goldfields St Ives grinding circuit.

Due to the limited surge capacity it was important to establish very good control of the grinding circuit to minimise:

1. The effect of disturbances to the grinding circuit
2. Grinding circuit disturbances sent to the leach feed

Prior to engaging Manta Controls, the grinding circuit was being operated according to the original control strategy of the SAG mill and classification circuit as per the design control philosophy.

Manta Controls redesigned the entire control strategy for:

1. The coarse ore feed system
2. The classification circuit
3. The SAG mill

**The Coarse Ore Feed System**

The initial control of the coarse ore feed system used an operator selected feed setpoint which manipulates the feeder outputs via a configurable feeder ratio. This required the feeders speed control to be in auto mode. When a feeder was changed from auto to manual, the feeder speed was changed to the raw ratio value. eg if the auto feeder ratio was 20% and the feeder speed was operating at 5%, when the feeder was placed in manual mode the feeder speed would step up to 20%. This caused significant feed disturbances and made operator control difficult.

When the feeders were in auto mode, a feeder trip would not be corrected until the loss of feed was noticed on the weightometer. This is a common problem with large dead time systems and can be corrected by utilising the principles of dead time compensation.

The Manta Cube feed controller accounts for feeder trips and provides bumpless transfer for all feeders. ie, a change from one control mode to another no longer creates any disturbance. Also a feeder trip causes only a minimal disturbance. Improvements in the ore feed system at St Ives, exhibit a similar behaviour to that shown in Figure 5.

**The Classification Circuit**

Since the St Ives SAG mill operates as a single stage SAG mill in closed circuit, any disturbances passed onto the classification circuit return to the SAG mill. Therefore it is critical to dampen out disturbances that may be fed to the hydrocyclones.

The entire classification control system was redesigned utilising the standard Manta Controls classification strategy. Areas that were improved were,

1. Improved SAG mill feed density control utilising cyclone underflow density and other water sources reporting to the feed
2. Cyclone feed flow rate stabilisation utilising surge control of the cyclone feed hopper



3. Cyclone pressure control utilising automatic on/off control of the cyclone feed valves
4. Grinding circuit particle size control utilising cyclone feed density and cyclone pressure control

The improvements made in the classification area were remarkable with stable control of the cyclone feed flow rate, cyclone feed density and cyclone operating pressure between the allowed 15 kPa pressure band. An additional side benefit was reduced cyclone feed pump wear / mechanical failure. The rebuild of the cyclone feed pumps was reduced considerably due to the consistent operation of the cyclone feed pressure as a result of good surge control of the cyclone feed hopper.

**The St Ives SAG Mill**

Operational data was collected for a month prior to the installation of the Manta Cube. The four sets of SAG operational data are again graphed as histograms and are shown in Figure 13. The wide variation of mill weight is again noticed which is becoming a signature of operator controlled SAG mills.

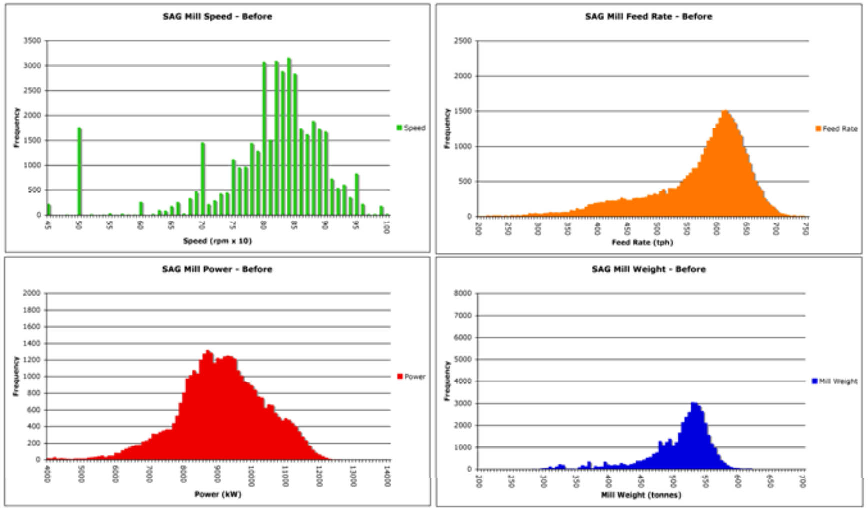


Figure 13. The performance of the Goldfields St Ives SAG mill – before the Manta Cube was implemented.

The Manta Cube was configured on the St Ives SAG Mill. Mill performance data was again analysed for a one month period, shown in Figure 14 (next page). During this time the Manta Cube was the only modification made to the SAG mill. Similar to the operation of the Telfer SAG mills, the mill weight is tightly controlled around the required set

point. Again the control system works the mill harder by operating at a higher speed range.

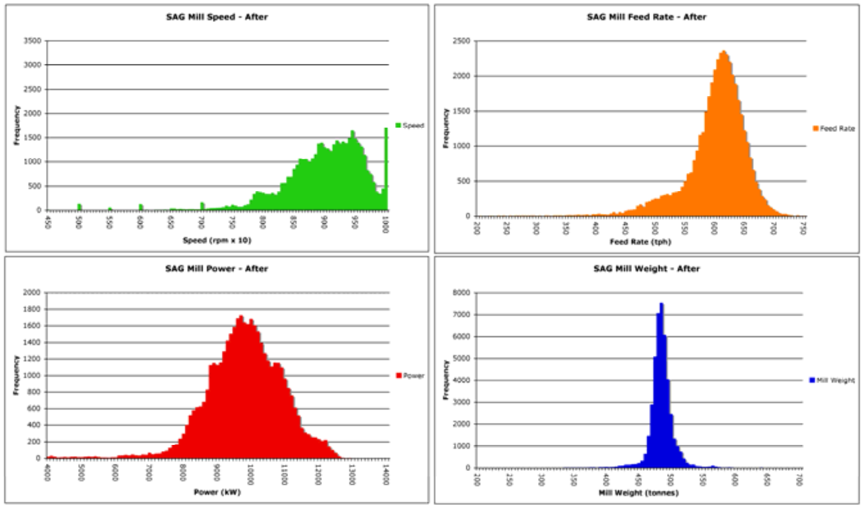


Figure 14. The performance of the Goldfields St Ives SAG mill – after the Manta Cube was implemented.

Variations of feed type are also present at St Ives arising from natural variation of ore types from the mine and direct tipping at the primary crusher. As described previously, the Manta Cube self compensates for these variations with the result being a stable SAG mill weight.

The variability of the mill weight again reduced considerably, thus stabilising the grinding circuit as well. This additional benefit of stable mill performance is quite pronounced downstream from the SAG mill. Improvements in the leach circuit due to the stable operation of the SAG mill was not quantified in this study.

With the improved control of SAG mill weight, the Manta Cube was able to increase the overall feed rate to the SAG mill as shown in the feed rate histogram of Figure 14.

The improved performance of the SAG mill after only one month of operation with the Manta Cube was calculated as a 6.1% increase in mill throughput.

## SUMMARY

Newcrest Mining Telfer Operation and Goldfield St Ives provide excellent examples of today's plant design. The emerging challenges presented by streamlined plants demand higher control performance. The Manta Cube successfully overcomes these issues using a unique control algorithm implemented locally on the user's plant control system.



The Manta Cube has proven itself to handle the common issues facing SAG mill designs, such as:

1. Coarse ore feeders trips
2. Ore type variations
3. Limited surge capacity in the recycle crushing circuit
4. Intermittent recycle crusher operation

The Manta Cube provides additional benefits in operability by working directly on the local plant control system. A platform independent control algorithm, the Manta Cube removes the cost and complications associated with traditional, standalone expert systems. Local implementation provides operators and technician alike with reliable access to detailed information on their SAG mills.

By using the Manta Cube both Newcrest Mining and Goldfields have achieved greater grinding circuit stability, tight mill weight control and higher throughput. Their SAG mills are working harder, continually pushing for higher feed rates and consistently utilising the available power draw. Goldfields St Ives recorded an immediate and sustained increase in throughput of 6.1%.

The design and construction of new mineral processing plants presents increasing pressure for reduced capital and operating costs by eliminating such things as feed blending and recycle surge capacity.

High performance control systems such as the Manta Cube have become more than a nice to have, but rather a necessity for optimal operation of minerals processing plants.

## ACKNOWLEGEMENTS

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The efforts of all the Telfer and Lefroy processing teams is also acknowledged for their valuable input during commissioning of the Manta Cube that have made the projects a success.