DEBOTTLENECKING COARSE ORE CONVEYOR SYSTEMS

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Mining companies are looking at maximising the capacity of their existing mining operations. Single train crushing and conveying systems are typically used to deliver ore from the mine to the concentrator. Increasing the existing system capacity is preferred over duplication of the system.

System capacity is increased by:

- Increasing the fragmentation of the ore to extend the primary crusher capacity
- Increasing the speed, power and bed depth of the feeders delivering ore from the crusher to the conveying system
- Increasing the speed, drive power and strength rating of the belt conveyors
- Installation of additional stockpile capacity

This paper discusses the analyses required to verify the maximum capacity that can be achieved by coarse ore conveying systems. The analyses include:

- Field measurement of crusher capacity
- Confirmation of field measurements by process simulation
- Crusher surge bin level control
- Bulk density
- Conveyor belt DIN f value

Dynamic modelling of the coarse ore system is used to determine the average daily sustainable capacity. The annual amount of ore processed is affected by the restrictions imposed by upstream and downstream operations. Extension of the dynamic model to include the downstream milling and concentrating circuit and the impact on amount of ore processed is discussed.

1. INTRODUCTION

With the steep change in commodity prices for copper and other base metals over the last decade, economic reserves at many mines have increased dramatically. As a result, many mining companies are focusing on expanding the capacity of their existing mines and concentration plants. Expanding existing operations rather than establishing new developments reduces the environmental and social risks involved in obtaining regulatory approval. Upgrading existing infrastructure also costs less than developing it from scratch.

Developers of new projects want confirmation that target production rates can be achieved, as well as understanding how bottlenecks impact on future production increases. This paper looks at the crushing and delivery of ore to the concentrator milling circuit, discusses the analyses required and the simulation tools available to determine system bottlenecks and establish ultimate plant capacity.

A typical open pit base metal mine and concentrator has the following elements:

- Drilling and blasting
- Truck/shovel fleet for ore and waste
- Primary crusher and coarse ore conveying to stockpile
- Stockpile reclaim and additional crushing and/or milling
- Flotation and separation of concentrates from tailings
- Concentrate thickening, filtering and transport to the smelter.

Significant capital cost savings can be achieved if the existing equipment is upgraded to handle the new capacity, eliminating the need to duplicate the system. The lessons learned during the analysis of existing systems can help improve the design of new systems. Understanding the bottlenecks that limit plant capacity allow them to be removed and/or provisions made to remove them with minimal impact on project cost and schedule.

Analyses of a number of concentrators have been performed to determine:

a. Maximum ore processing capacity of the current configuration
b. The bottlenecks that limit production
c. Capacity increases achievable with bottleneck removal.

This paper focuses on the capacity analysis of the primary crusher and coarse ore conveying system to stockpile using:

1. Existing metallurgical data
2. Reliability and availability data
3. Field measurements
4. Crusher and conveyor analysis programs
5. System analysis using dynamic simulation.

The limitations that downstream processes impose on the crushing and conveying system capacity are also discussed.

2. CRUSHING AND COARSE ORE CONVEYING SYSTEM

The analysis of the capacity of a particular ore crushing and conveying system depends on a number of factors. Figure 1 is a schematic showing the upgrade of a crushing and coarse ore conveying system with the new equipment, shown as clouded.

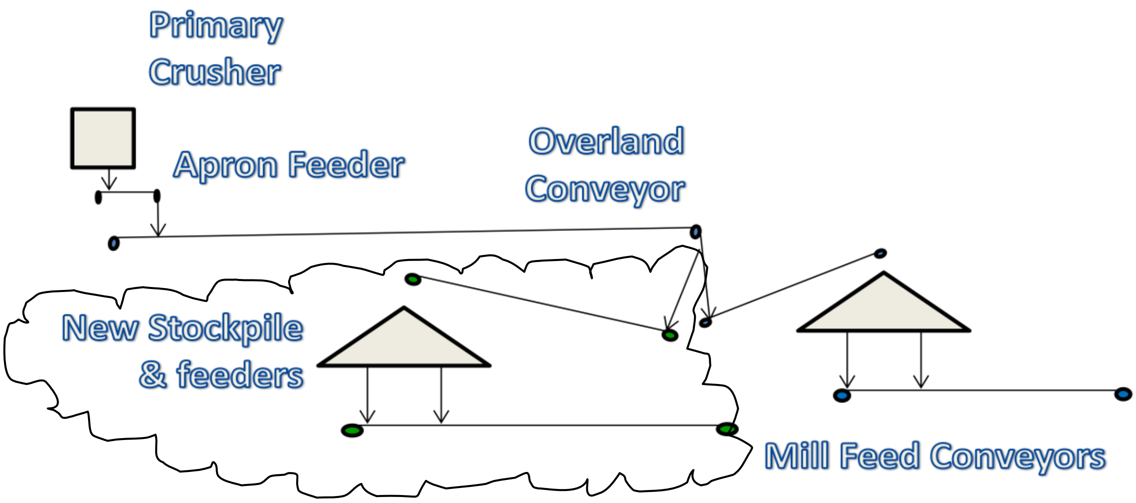

Figure 1. Schematic – Ore crushing and coarse ore conveying system upgrade

2.1 TRUCK DELIVERY

The availability of trucks to deliver ore to the primary crusher dump pocket plays a critical role in total crusher capacity. Work rules regarding shift change, lunch breaks, crew meetings, other human factors and work stoppage during blasting in an open pit mine often reduce the daily hours that trucks can dump to 20 hours or less. The minimum time between truck dumps depends on the truck, the traffic pattern around the crusher and whether two sided dumping is available. The loaded truck capacity is the last piece of information required.

The following inputs allow analysis of the crusher and coarse ore conveying system capacity:

- Dump hours per day
- Time between truck arrivals
- Truck capacity

Analysis of truck delivery to the crusher is a complex issue and beyond the scope of this paper.

2.2 CRUSHER

Crusher instantaneous capacity is dependent on the properties of the ore being handled. Mines often have multiple ore types with a different crushing capacity for each ore. Overall crusher throughput is reduced by the following factors:

- Truck availability to feed the crusher
- Downtime for scheduled and unscheduled maintenance
- Operational restrictions

The reductions due to truck availability are discussed briefly in Section 2.1 but are beyond the scope of this paper. Crusher capacity and operational restrictions are discussed below.

Crusher Capacity

The primary crusher instantaneous or maximum capacity is dependent on:

- Ore hardness
- The particle size distribution (PSD) of the run-of-mine (ROM) feed to the crusher

Hardness is relatively easy to measure and usually already known. PSD, on the other hand, is more difficult to predict and is not usually identified until ore has been produced and its PSD measured. In the design stage, the tendency is to be conservative and use a PSD that is on the coarse side. The actual ROM PSD produced by the mine, especially when optimised after drilling and blasting, often turns out to be much finer than the PSD assumed in design. Crusher capacity increases with a finer feed. It is not uncommon for primary crusher instantaneous capacity to be 30% greater than assumed in design. There are instances where crusher capacity is almost twice the design capacity, attributable primarily to a feed PSD that is much finer than that on which the design was based.

When analysing existing operations, videos of the trucks dumping and emptying the crusher feed pocket are used to determine crusher capacity. Videos of trucks delivering the major ore types to the crusher are filmed and an average instantaneous crusher rate for each ore type is determined using:

- Truck capacity
- Time the crusher takes to process the ore from the time it first sees feed until it is empty

Where the PSD of either the crusher feed or product is available, there is good agreement between the crusher capacity predicted using simulation software and the actual measured capacities.

Operational and Maintenance Restrictions

The surge bin under the crusher introduces the following constraints into the system:

- Truck dumping can start only after the surge bin has the capacity to accept a full truck load
- The requirement to maintain a minimum level in the bin
- The capacity of the feeder discharging the bin
- Feeder ramp-up time from zero to full speed when the feeder is stopped due to low level

A 3D model (Figure 2) of the surge bin live capacity is used to produce a bin capacity versus percentage level curve. The model is based on withdrawal angles of 60 and 70 degrees with four conical piles (under crusher discharge annulus) at the surcharge angle on the top surface (Figure 3). This matches visual observations of the crusher surge bins in operation.

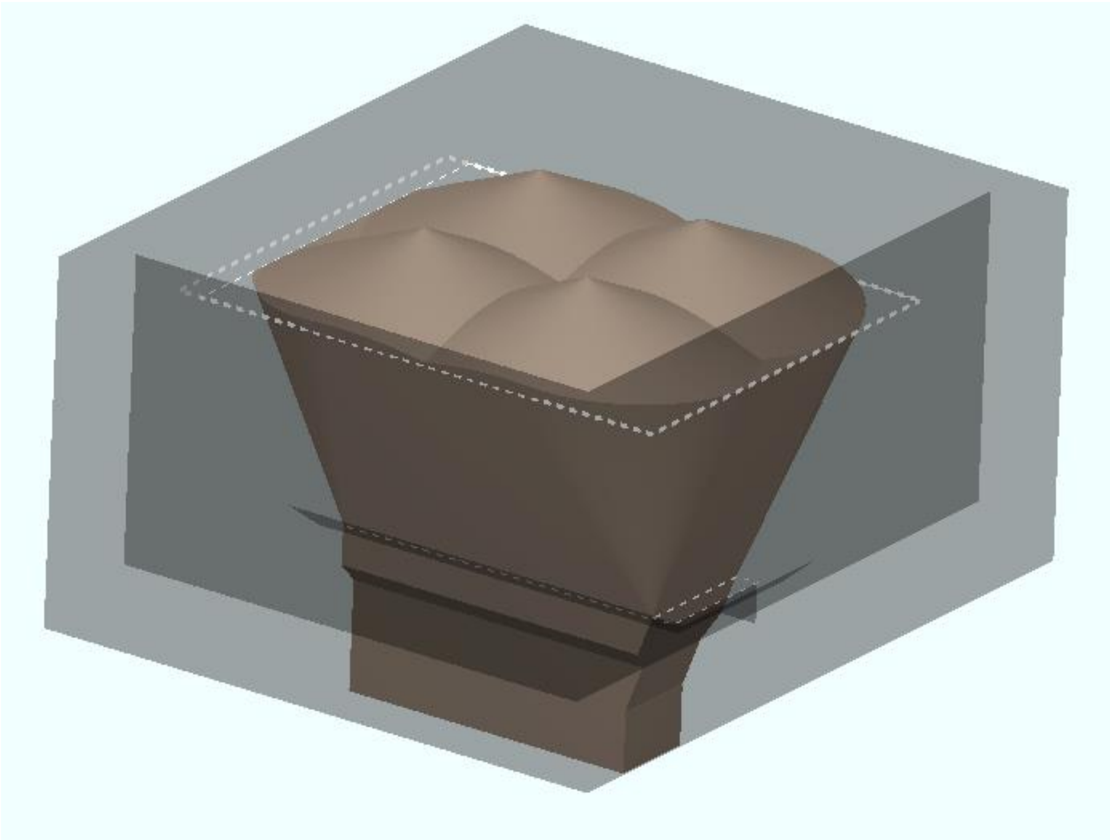

Figure 2. 3D view of typical surge bin live capacity

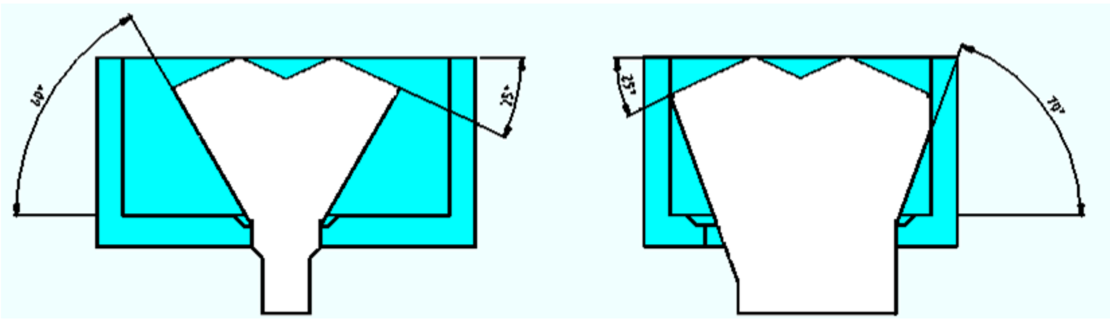

Figure 3. Typical surge bin live capacity geometry

Surge bin live capacity of twice the truck capacity is common. A typical truck dump control permits trucks to dump into the surge bin when bin level drops to 50%. The surge bin level drops when trucks are not available to deliver ore to the crusher and the feeder is stopped when it reaches a minimum level. This is done for two reasons:

- To prevent feeder damage due to coarse ore impact on the empty feeder
- To prevent problems with feeder start-up because of the high start-up torque (the result of the high pressures produced at the feeder by the impact of the crusher discharging onto the empty feeder).

A minimum bin level of 20 to 30% prevents these start-up problems. When the feeder is restarted, its speed is increased slowly from zero to full speed with ramp-up times as long as 120 seconds.

These restrictions, along with the downtime due to scheduled and unscheduled maintenance, reduce the crusher throughput.

2.3 SURGE BIN DISCHARGE FEEDER

The surge bin discharge feeder is typically apron or belt. Maximum feeder capacity needs to be determined to see if it is the bottleneck in the system. In an existing operation the best method for determining the maximum capacity of the feeder is to correlate the tonnage measured by the weigh scale on the conveyor downstream of the feeder with the feeder speed setting. It is also important to confirm that there is sufficient power available to run the feeder at full speed.

Accurate estimates of feeder capacity can be made if bed depth, feeder speed and the bulk density of the ore on the feeder are known.

Bed Depth
Normal limits for apron and belt feeder speed and bed depth are shown in Table 1.

	Apron Feeder	Belt Feeder
Maximum Bed Depth	75% of skirt width	50% of skirt width
Maximum Speed	.3 to .4 m/s	.75 m/s

Table 1. Feeder design parameters

When operators are pushed for more production, these limits often get increased. Field modifications to apron feeder striker plates are known where the bed depths have been increased to 122% of the skirt board width (a 63% increase in bed depth and capacity).

Feeder Speed
The speed of an existing feeder should be checked in the field. This is especially critical if the drives have been upgraded. It is not uncommon to find that the actual maximum speed does not match what is shown on the data sheet.

Bulk Density
On existing installations, with weigh scale data available, best practice is to back calculate the bulk density using the measured feeder speed and known bed depth.

If flow property measurements of the bulk density of the fines are available, the bulk density based on an effective head of 6 metres gives results that match those back calculated from feeder speed and belt weigh scale readings. Bulk densities 12% to 15% below actual are predicted when the bulk density is based on an effective head of 0.8 metres. A low bulk density estimate results in feeder and conveyor capacity underestimation.

Bulk density measurements using 20 litre containers (or larger) overstate the density that feeders and conveyors experience. A bulk density of 85% of the field-measured result matches those back calculated from feeder speed and belt weigh scale readings. If the only information available is the particle specific gravity, estimate the bulk density at 62% of the ore S_g to account for voids between the lump ore.

2.4 CONVEYING SYSTEM

The conveying system downstream of the crusher surge bin is another potential bottleneck. Conveyor capacity is dependent on a number of factors:

- Belt speed
- Maximum allowable cross-sectional load on the belt (% of CEMA)
- Power available
- Belt strength rating and safety factors
- Take-up tension available to prevent belt slip

Existing overland steel cord belt conveyors with vulcanised splices are often run at lower speeds with higher belt safety factors than conveyors designed today (for example, speeds of less than 4 m/s with a belt safety factor of 6.7). Steel cord belts running at 7 m/s are not uncommon in current times. Advances in testing and understanding of steel cord vulcanised splices and pending revisions to design codes allow consideration of lower steel cord belt safety factors. One operating overland steel cord belt conveyor´s design basis set the minimum safety factor at 5.5.

Plans to upgrade existing systems need to factor in the impact of lost production. Extended shutdowns are not acceptable to operations and any shutdown needs to be scheduled to coincide with required maintenance shutdowns (mill liner replacement for example).

Increasing the capacity of those conveyors with a dual drive primary pulley and single drive secondary pulley can be accomplished in limited time. This is done by installing new, larger diameter pulleys (to increase the belt speed) and adding a second drive to the secondary pulley. A 33% increase in capacity is obtainable since both power and capacity are proportional to speed. Adding additional drives and pulleys or replacing existing drives may require extended shutdowns which are best avoided.

Figure 4 shows the schematic of an overland conveyor whose belt velocity was increased by 31% through replacing the drive pulleys with larger diameter pulleys with larger shafts. The power for this conveyor increased 33% after the installation of a fourth motor on the secondary drive pulley. A higher strength belt and tensioning system is required to maximise capacity.

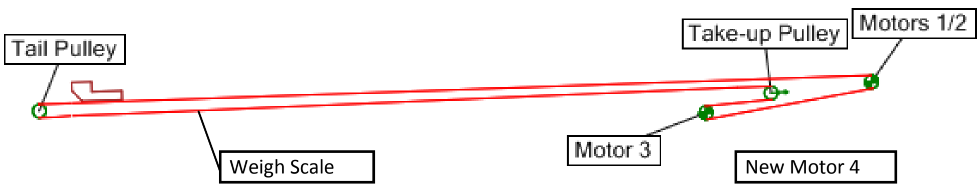

Figure 4. Overland conveyor schematic

Field measurements of the motor power draw and tonnage for this conveyor are plotted in Figure 5. This conveyor had been in operation for over 10 years at the time of measurement. The conveyor parameters were input to a conveyor design package and the DIN analysis results have also been plotted. The scatter in the measured results happens, in part, because the weigh scale and power data is taken once every 84 seconds and the tonnage is estimated using an algorithm to account for the ten minutes the ore is on the conveyor.

The limit on the measured tonnage is a result of the speed limit placed on the apron feeder to prevent overstressing the belt. The higher strength belt required by the addition of the fourth motor had not been installed when the measurements were taken.

The default DIN f value of 0.02 bounds the scatter on top and indicates the conveyor has a maximum capacity of 9,800 tph using 100% of the installed power. The power draw with a DIN f value of 0.0164 gives the best fit to the measured power draw with the ratio between them of 1.22.

Common practice is to calculate conveyor power with a “normal” DIN friction factor f=0.02 and with a “high” (+15%) and a “low” (-15%) value. The conveyor capacity is then selected to limit the power calculated with the “high” f value of 0.023 to 90% of installed power. Application of this practice results in a conveyor capacity of 8,000 tph (82% of the actual 9,800 tph capacity).

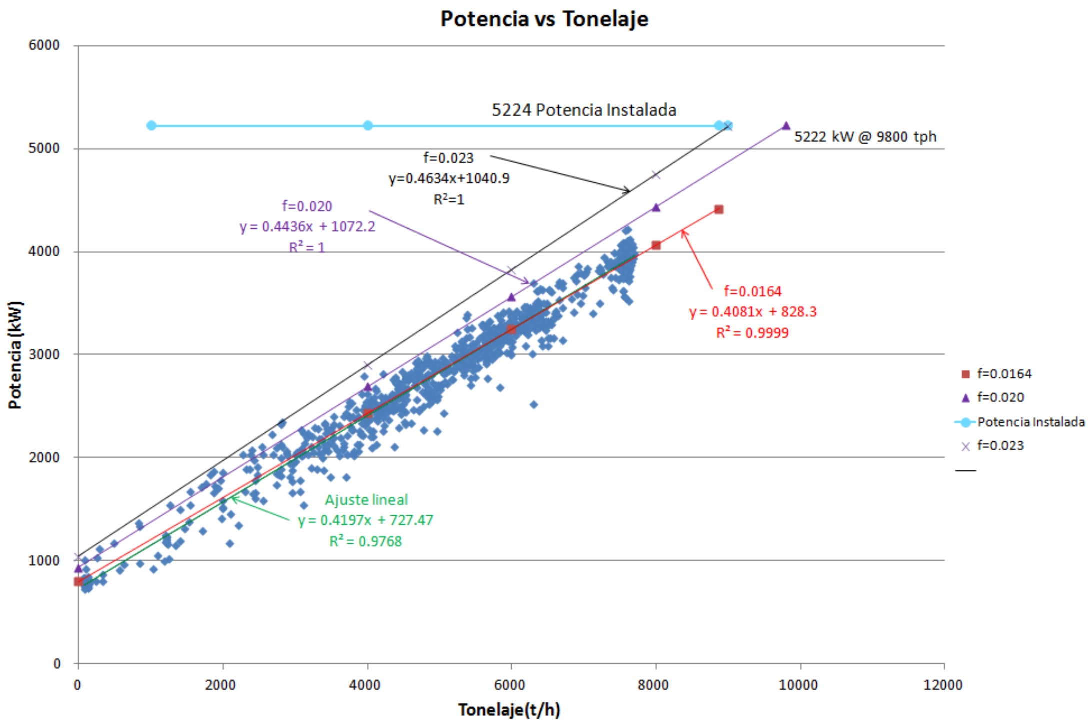

Figure 5. Overland conveyor field-measured and calculated power draw

3. SYSTEM SIMULATION

Dynamic simulation is the preferred methodology for evaluating complex systems because, unlike spreadsheet models or linear programming, it captures the dynamic effects of the system and quantifies the cumulative capacity losses associated with them. These dynamic effects include: interactions, process variation, random failures, competition for resources, logistical constraints, process constraints, control logic decisions that take place over time and other phenomena observed in real systems.

In addition to the planned shutdowns, the model randomly shuts down the various pieces of equipment based on their mean time to failure. It keeps the equipment shut down for a length of time based on the mean time to repair. It keeps track of the cumulative production losses for each run. The simulation model is run multiple times to gain a statistically accurate average ore processing rate.

3.1 PRIMARY CRUSHER

Preparation of a dynamic simulation model of the crusher through to stockpile material handling system is the next step in the analysis of the system capacity. In addition to limited truck dumping hours, variability between mean truck arrival times, random equipment failures based on mean time to failure and shutdowns based on mean time to repair, this model included the following logic:

- Truck dumping is not permitted until the surge bin can accept a full truck load.
- Feeder slows and stops at low bin level (see discussion in Section 2.2)
- Feeder ramp-up rate of two minutes (0 to 100% of speed)
- Feeder volumetric capacity and the bulk density of the ore determine feeder tonnage capacity

The information in the following Table and Figures is normalised as follows.

1. Target average daily processing capacity = 100%
2. Individual equipment capacity = per cent of target capacity if operated 24 hours per day

Description	% Daily Target Capacity
Hard Ore Bulk Density – t/m^3	***2.04***
Conveyor Capacity – Hard Ore @ 80% CEMA	***141.5%***
Feeder Capacity – Hard Ore @ 100% Speed	***150.6%***
Crusher Capacity – Hard Ore	***158.4%***
Soft Ore Bulk Density – t/m^3	**1.99**
Conveyor Capacity – Soft Ore @ 80% CEMA	**138.1%**
Feeder Capacity – Soft Ore @ 100% Speed	**147.1%**
Crusher Capacity – Soft ore	***238.4%***
Conveyor Capacity @ 100% installed power	**156.4%**

Table 2. 24 hour per day equipment capacities as percentage of target capacity

Inspection of Table 2 indicates that the optimisation of the mine drilling and blasting increased the crusher capacity such that, even with upgrades, the conveyor (80% of CEMA) and then the feeder (100% speed) are the bottlenecks in the system.

The feeder is the real system bottleneck as the conveyor capacity limit is a soft limit based on percentage fill. Power is not a problem for this system as the feeder is not capable of delivering sufficient ore to the conveyor to trip the motors. At 100% feeder speed the belt conveyor loading is 83% of CEMA with a maximum power draw of 94% of the installed power.

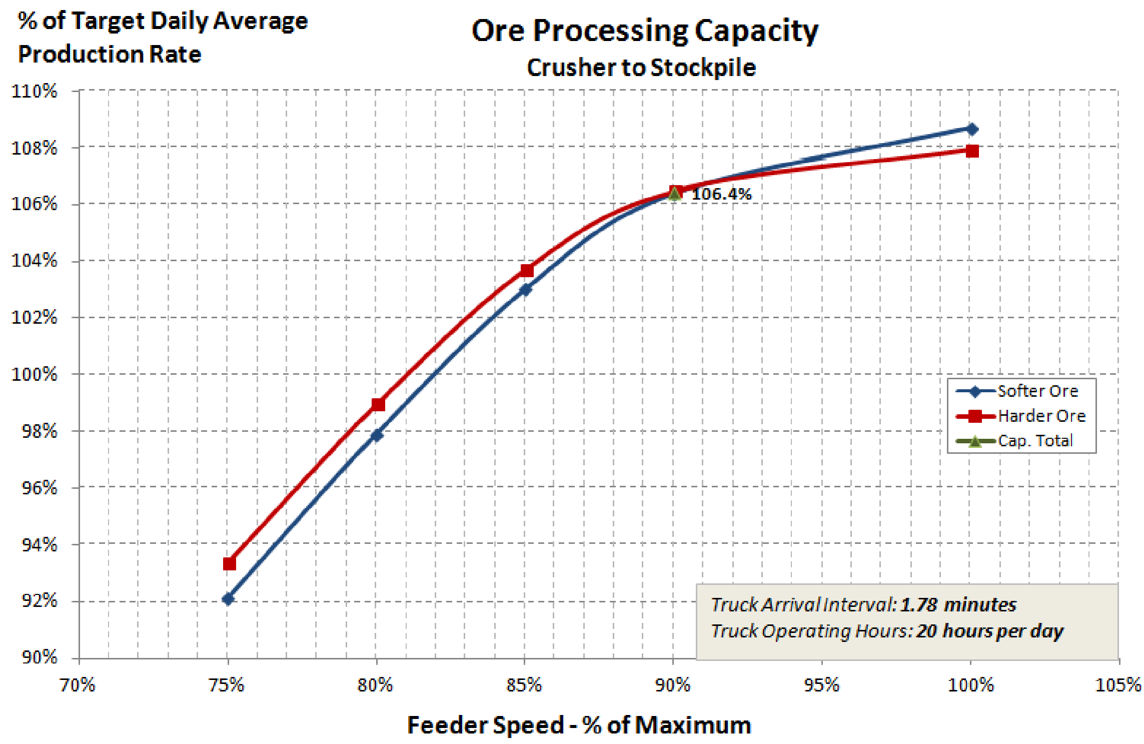

Figure 6. Crusher system model results

Figure 6 demonstrates the model results when running the simulation at different percentages of maximum feeder speed settings with the hard and soft ore.

The model indicates that the crusher system can exceed the target capacity by 108% if there are no downstream restrictions. The model results closely match actual production figures over a selected nine day period with the concentrator operating normally.

It is interesting to note that the system processing capacity on the harder ore exceeds that of the softer ore up until 90% feeder speed settings. The higher bulk density of the harder ore offsets its lower crushing rate at lower processing rates.

The ore processing capacity of the system is linear up to 85% of maximum feeder speed. At feeder speeds over 85% of maximum, the operational restrictions and equipment capacity limits come into play and the capacity curves level off. The impact is more pronounced for the harder ore due to its lower crushing capability.

3.2 SYSTEM SIMULATION WITH DOWNSTREAM RESTRICTIONS

The inclusion of downstream restrictions gives the model a more realistic behaviour because the limitations due to downstream equipment capacity are considered along with the equipment availability. The simulation captures the cumulative capacity losses associated with both and gives a more accurate calculation of the average system capacity.

The integration of the crushing model with the dynamic model of the concentrator plant included the following systems and processes:

- Coarse ore stockpile
- SAG mill grinding circuit
- Ball mill grinding circuit
- Flotation circuits
- Regrind circuits
- Thickening and filtering circuits
- Scheduled shutdown for major equipment
- Random failures for all equipment
- Equipment rates variability
- Ore head grade variability
- Various storage capacities
- Various control logics

The dynamic effects and interactions between all the process and interruptions were captured and quantified, allowing a realistic assessment of the type of production performance that could be expected.

Figure 7 displays a screenshot of the complete concentrator plant simulation model.

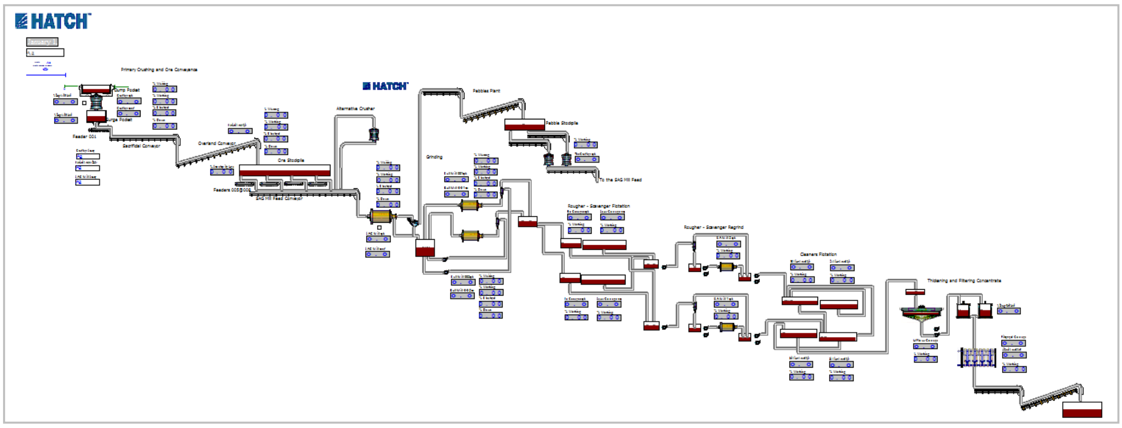

Figure 7. Screen plot of concentrator plant simulation model

As the model runs, detailed statistics are displayed on the screen to facilitate understanding of the equipment usage, throughput, storage levels, blockages, and starvation periods. This is used to increase understanding of the dynamic behaviour of the system over time, assist in model verification, and ultimately determine the system capabilities and constraints.

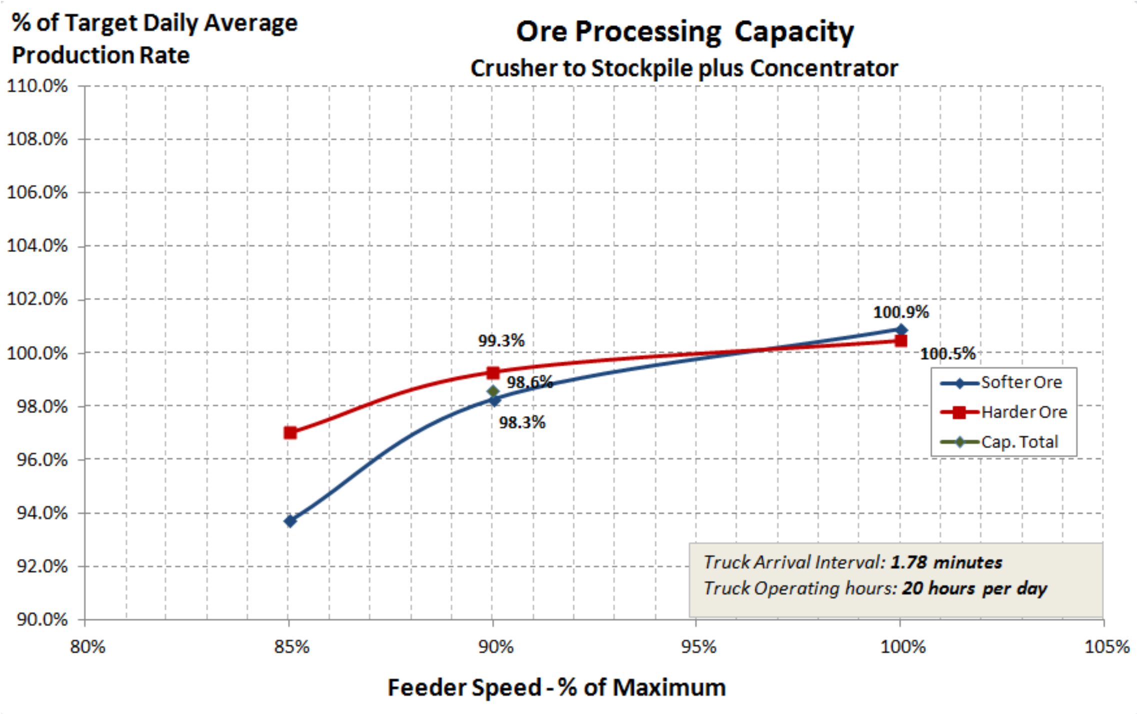

Figure 8. Complete crusher system and concentrator plant model results

Figure 8 shows the model results when running the complete dynamic model from the crusher to concentrate storage. The desired system capacity is achievable with the feeder at 96% of maximum speed.

The introduction of the downstream restrictions reduces the processing capacity by 7.3%. The maximum average daily ore processed works out to 67.3% of the maximum capacity of the system bottleneck (the feeder).

The restrictions in the system can be split into three groups:

▪ The upstream truck delivery restrictions	16.7%
▪ Crusher system operational and availability restrictions	10.9%
▪ Downstream processing restrictions	5.1%
Total	**32.7%**

The above percentage figure, when multiplied by the "Percentage Daily Target Capacity" of the bottleneck in the system (the feeder), give the losses attributable to each of the three groups.

4. CONCLUSIONS

Analysis of the capacity of a coarse ore crushing and conveying system requires an accurate determination of the maximum capacity of the individual pieces of equipment (crusher, feeder and conveyors). Traditional analysis methods have been shown to underestimate equipment capacity. Causes of understatement of equipment capacities are:

- PSD of the crusher feed (use of a coarse PSD underestimates crusher capacity)
- Belt conveyor DIN f value (use of the “normal f=0.02”, “high” and “low” DIN friction factor overestimates conveyor power draw and underestimates the conveyor capacity)
- Bulk density of the ore (use of a low effective head to estimate the bulk density produces low bulk densities, which underestimate the capacity of feeders and conveyors).

When accurate equipment capacity limits are available (field measured and confirmed), dynamic simulation results closely match actual system performance.

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