KEY PRODUCTION DRIVERS IN IN-PIT CRUSHING AND CONVEYING (IPCC) STUDIES

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1. Introduction

During the last 12 months, Sandvik's Technical Service Group has carried out nine Scoping and Pre-feasibility studies for the application of In-pit crushing and conveying (IPCC) for large mining companies; the majority in conjunction with the Snowden Consulting Group. During these studies several key and recurring drivers have been identified:

1. Mining schedule issues – there are several issues which crop up repeatedly, including:
    - the unnecessary curvature of pit walls,
    - very high rates of vertical advance which are (created by schedule optimisers to minimise stripping at all times) which are at the limit of what can be realistically achieved (and which of course make it harder for IPCC to achieve any impact), and
    - The allocation of material to semi-mobile systems to maximise the ability for IPCC to be an effective alternative.
2. IPCC productivity issues – the key issues are the IPCC system operating hours achievable, and the system throughput (both instantaneous and the average).
3. IPCC Risk issues – there are perceptions about the risks associated with the use of IPCC which are a mix of reality and fiction, but which nonetheless create negativity towards the use of IPCC.

In this paper, the authors wish to address specifically the factors affecting the IPCC productivity.

2. IPCC system operating hours

In order to establish realistic estimates for the effective operating hours for an IPCC system, and also the hours that the system has to run to achieve those effective hours (the Service Meter Unit or "SMU" factor), it is necessary to derive the appropriate hours for each part of the IPCC "chain", and then assess how they interact. This in turn requires that we have a "normal" way of deriving and stating effective operating hours.

What is clear in the mining industry is that there is no standard way of deriving or stating this data! Most large mining companies have their "standard" nomenclature which makes use of reporting systems (e.g. Modular Mining) to provide data which forms the basis of the calculation process.

Availability

Figure 1 shows an example of derivation of the availability for each relevant component of a mining system incorporating either semi-mobile IPCC (SMIPCC) or fully mobile (FMIPCC). These components comprise the shovel, crusher station, conveyors and spreader(s); and in the case of the semi-mobile crushing also the trucks feeding the dump pocket.

Figure 1 Example of Availability for IPCC Components

IPCC Operating Hours		Shovel	Truck	SM Crusher	FM Crusher	Conveyors	Spreader	SM COMBO	FM COMBO
Availability									
Calendar Hours	hours	**8,760**	**8,760**	**8,760**	**8,760**	**8,760**	**8,760**	**8,760**	**8,760**
Scheduled non-work time	hours	96	96	96	96	96	96	96	96
Wet weather losses	hours	192	192	96	96	0	192	192	192
Crusher Relocation losses	hours	0	0	336	96	192	0	336	192
Industrial losses	hours	0	0	0	0	0	0	0	0
Scheduled Hours	hours	**8,472**	**8,472**	**8,232**	**8,472**	**8,472**	**8,472**	**8,136**	**8,280**
Daily Service	hours	365	365	365	365	183	365	365	365
Weekly Maintenance	hours	312	312	312	312	312	312	312	312
Annual Maintenance Shutdown	hours	168	168	336	336	0	168	336	336
Scheduled Maintenance	hours	845	845	1,013	1,013	495	845	1,013	1,013
Scheduled Availability	%	90.0%	90.0%	87.7%	88.0%	94.2%	90.0%	87.5%	87.8%
Breakdowns as % of Scheduled	%	4%	4%	4%	4%	2%	3%		
Breakdowns	hours	339	339	329	339	169	254	407	678
Overall Availability	%	86.0%	86.0%	83.7%	84.0%	92.2%	87.0%	82.6%	79.6%
Available Hours	hours	**7288**	**7288**	**6890**	**7120**	**7808**	**7373**	**6716**	**6589**

Key observations from this figure include:

a) The scheduled availability of the individual components of an operating system incorporating a crusher system is always higher than the combination of the system – as one would expect. Sandvik currently allow the system to take on board the maximum scheduled downtime of any of the components – a little conservative but reasonable.

b) A key component of the Scheduled hours is the time allowed or required for the relocation of the crusher stations during the year. In large mines, it is possible to have enough material per bench in a cutback to balance haul distances (and hence truck numbers) with limiting crusher relocations to every 45 to 60 metres vertically, which equates to +/-twice a year. The Sandvik experience at the Mae Moh mine in Thailand[1] has shown that two semi-mobile crushers can be relocated in 7 working days (168hrs). Verbal advice from other companies regarding the time taken to relocate gyratory crushing stations at Escondida and other sites (personal communication) also suggests that 7 days is adequate for a single gyratory relocation. Sandvik have prepared a detailed schedule for our studies requiring 7 days, but we typically allow 10 days per relocation to be conservative in calculating effective operating hours.

c) In the case of a FMIPCC station, it is always moving and only needs to relocate from one bench to another from time to time, with the track-shiftable conveyor relocation and splicing determining the time required. Hence the 8 days (192hrs) allowed here is a reflection of 2 x 4 days to move the conveyors and re-splice the belts, etc.

d) The breakdown time allowed for an SMIPCC system is different from a FMIPCC system. The question is how much interaction and interdependence exists between the breakdown of a shovel or truck and the IPCC components?

- For a SMIPCC system the interaction is not simplistic in that it is a function of the length of a breakdown, and whether during a breakdown of one component there is the time or the manpower to do opportunity maintenance on other components that thereafter reduces the probability of an independent failure.

Sandvik have reviewed limited available output from operating mine systems, and determined that there will be some impact on downtime of a SMIPCC system due to shovel breakdown, but that it is not justified to assume that all breakdowns of both the shovel and crusher will be additive. In discussion with clients we have assumed a 20% "overlap" between a shovel and crusher downtime, but no additional downstream impact.

- For a FMIPCC system, 100% "overlap" or interdependence is applied, which assumes that no opportunity maintenance is done on the crusher when the shovel is down, or vice-versa. Hence the downtime for the system is the sum of the shovel and the crusher/sizer downtime.

Utilisation

Once the available hours have been established, it is necessary to determine the utilisation of the equipment. The normal approach to determining this is to determine the stoppages that occur in a shift, and hence each day. Figure 2 shows an example of such an assessment for the components of an IPCC system.

Figure 2 Utilisation calculations for IPCC components

IPCC Operating Hours		Shovel	Truck	SM Crusher	FM Crusher	Conveyors	Spreader	SM COMBO	FM COMBO
Utilization									
Shift duration	hours	12	12	12	12	12	12	12	12
Shift duration	mins	720	720	720	720	720	720	720	720
No of shifts/day		2	2	2	2	2	2	2	2
Shift Change	mins/shift	10	10	10	10	10	10	10	10
Equipment Inspection	minutes	10	10	10	10	10	10	10	10
Meal break	minutes	40	40	40	40	40	40	40	40
Blasting delays	minutes	13	13	13	13	13	0	13	13
Fuel/Lubrication	minutes	15	25	15	15	0	0	7.5	15
Manoeuvre	% of shift	4%	0%	0%	4%	0%	0%	0%	4.8%
Manoeuvre	minutes	28.8	0	0	28.8	0	0	28.8	34.6
Other delays	minutes	20	0	0	0	0	0	0	20
Effective Operation/Shift	minutes	583	622	632	603.2	647	660	610.7	577.44
Equipment Utilization	(%)	**81.0%**	**86.4%**	**87.8%**	**83.8%**	**89.9%**	**91.7%**	**84.8%**	**80.2%**

Once again, the important issue is to understand the interaction between the various components of an IPCC system. Key observations from this figure include:

a) Blasting delays - Allowances have to be averaged – in this example a 1hr blasting delay three times per week (180 minutes) translates into 26 minutes per day or 13 minutes per shift that will be lost.
b) Fuel/lubrication time - it is necessary to separate diesel and electric equipment, and also to know the size of the fuel tanks and hence how frequently it is necessary to refuel. For most trucks, a 12 hour tank is installed, and the downtime is the time to divert to the refuelling station and refuel time. For the other IPCC components it is only necessary to allow time for lubrication and checks.

  - For a SMIPCC crusher, as it has a two or three truck dump pocket volume and multiple trucks hauling to it at any time, it is not necessary to have the machine down whilst individual trucks are refuelled. A simple increase to the routine pre-start inspection is deemed sufficient.

- For a FMIPCC crusher, the direct interaction with the shovel means that the crusher will lose some operating time whilst the shovel is down. Because it has a 2 to 3 pass dump pocket, it should have less downtime than the shovel, but Sandvik has assumed a full interdependence with the shovel.

c) Manoeuvring Time – A shovel spends time continually adjusting its position in the face, and this can be dealt with as part of the operating efficiency if desired. However, as it impacts the two types of IPCC differently we prefer to include it here as a utilisation factor.

- For a SMIPCC crusher there is no reduction in operating time at the crusher whilst a shovel manoeuvres, provided that either the feed bin capacity is sufficient to cover any lost time, or (as is generally more likely) that the crusher is fed by two shovels and the risk of them both manoeuvring at the same time is reduced. Generally it is felt that this is best dealt with by the ratio of instantaneous to average throughput rather than a reduction in operating time.

- For a FMIPCC crusher there will be more of an impact, once again depending on the size of the feed bin and its storage capacity. Typically for a larger unit matched to a large shovel, the feed bin is +/-300tonnes, which at a throughput (instantaneous) of say 7,500tph is sufficient for 2.4 minutes. This should cover some of the shovel delays, but of course if the FMIPCC unit needs to relocate at the same time to remain under the shovel; it is unable to manoeuvre wit a full bin unless the design allows this (as is the case with a recent Sandvik design where the feed bin is track-mounted). In most studies, Sandvik elects to take the full time lost to the shovel manoeuvring and an additional 20% as the total loss for the system.

Clearly, the best way to determine these losses is to undertake a simulation. However, in the earlier stages of study it is rarely possible to afford this, and once again any simulation is only as good as the accuracy of the data upon which it based! Fortunately, the available statistics from operating mines is sufficient to get good MTBF and MTTR data for the shovel/truck systems. The key is to understand the crusher system and less data exists to model this.

Overall operating hours

Figure 3 shows the summary of the combination of the Availability and Utilisation data for a SMIPCC and FMIPCC system.

Figure 3 Overall operating hours and SMU factors

IPCC Operating Hours		Shovel	Truck	SM Crusher	FM Crusher	Conveyors	Spreader	SM COMBO	FM COMBO
Effective Operating Hours									
Annual Hours	hours	8,472	8,472	8,232	8,472	8,472	8,472	8,136	8,280
Equipment Availability	(%)	86.0%	86.0%	83.7%	84.0%	92.2%	87.0%	82.6%	79.6%
Equipment Utilization	(%)	81.0%	86.4%	87.8%	83.8%	89.9%	91.7%	84.8%	80.2%
Factor for start up years		100%	100%	100%	100%	100%	100%	100%	100%
Effective Operating Hours	hours	**5,903**	**6,296**	**6,048**	**5,965**	**7,016**	**6,758**	**5,697**	**5,285**
SMU Factor		**1.10**	**1.04**	**1.08**	**1.16**	**1.10**	**1.08**	na	na

As would be expected, the shovels and trucks are demonstrating around the 6,000 to 6,300 hours of effective operation per annum, and the individual downstream components (conveyors and spreaders) the higher utilised hour potential which plant systems typically exhibit.

Once we combine these components we are able to model, in a fairly rudimentary way, the expected effective operating hours for a SMIPCC and FMIPCC system. The SMIPCC system effective hours are somewhat higher than the FMIPCC, and this is what we would expect due to its ability to maintain separation of the shovel/truck interaction from its operation. Of course this is tempered by the losses during relocation of the system. The FMIPCC demonstrates the lowest effective operating hours due to its intimate relationship with the shovel that is feeding it.

The SMU Factor

It is important to understand the relationship between the effective operating hours and the engine hours upon which the hourly operating cost estimates provided by Original Equipment Manufacturers (OEM's) are based. For example, tyre life for trucks, and Ground Engaging Tools (GET) for shovels are both measured based on engine hours of the equipment. Hence to simply take the effective operating hours of the equipment and multiply it by estimates provided by third parties (or indeed internal data) results in an underestimation of operating costs.

Another trap that the authors have become aware of is the tendency for companies to predict future fuel consumption on trucks by taking last year's total consumption and dividing it by the total engine hours on the truck fleet. This gives (surprise!) a lower number, which is often well as much as 20% below the actual fuel consumption that is modelled and which will be observed during operation, if there is substantial idle time on the fleet. If used in the comparison between IPCC and truck/shovel, this distorts the result wrongly in favour of trucks.

How is the relationship between effective hours and engine hours determined? It is actually quite simple – we need to calculate the times when the engine is running on a machine but it is not doing effective work.

Figure 4 shows the calculation for some of the equipment in a mine.

Figure 4 The SMU Factor calculation

IPCC Operating Hours		Shovel	Truck	SM Crusher	FM Crusher
Utilization					
Shift duration	hours	12	12	12	12
Shift duration	mins	720	720	720	720
No of shifts/day		2	2	2	2
Shift Change	mins/shift	10	10	10	10
Equipment Inspection	minutes	10	10	10	10
Meal break	minutes	40	40	40	40
Blasting delays	minutes	13	13	13	13
Fuel/Lubrication	minutes	15	25	15	15
Manoeuvre	% of shift	4%	0%	0%	4%
Manoeuvre	minutes	28.8	0	0	28.8
Other delays	minutes	20	0	0	0
Effective Operation/Shift	minutes	583	622	632	603.2
Equipment Utilization	(%)	**81.0%**	**86.4%**	**87.8%**	**83.8%**
SMU Factors					
Shift Change	mins/shift	OFF	OFF	ON	OFF
Equipment Inspection	minutes	ON	OFF	OFF	OFF
Meal break	minutes	OFF	OFF	ON	ON
Blasting delays	minutes	OFF	OFF	OFF	ON
Fuel/Lubrication	minutes	OFF	ON	OFF	ON
Manoeuvre	% of shift	ON	ON	ON	ON
Manoeuvre	minutes	ON	ON	ON	ON
Other delays	minutes	ON	OFF	ON	ON
SMU Factor		**1.10**	**1.04**	**1.08**	**1.16**

For each break which occurs in a shift, the service meter will either be running or not – and if engine hours are accumulating whilst no productive work is done, then this is part of the SMU factor. As an example, truck engines have a turbo timer of +/-5minutes. Even if the engine were turned off during refuelling as well as shift change and meal breaks, this would still give 3 x 5 = 15 minutes per shift of SMU factor, which in this case would be a little over 2% of the 12hr shift, or 3% of an 8hr shift. This then is the absolute minimum. In this example a factor of 4% is derived, but in some operations we have observed factors for the trucks of greater than 10%.

Of course, when the truck is idling, then its fuel consumption is minimal, so the full operating cost is not applied to the differential hours – only the relevant costs as supplied by an OEM.

We can apply the same procedure to all equipment in a mine, and typically drill rigs have the highest factors (due to the amount of time walking on and off blasts, etc), and lowest for trucks when they are used effectively. For the IPCC crushers, they like large shovels are generally run with electricity, and can be shut down more easily. However, there is a tendency to "idle" a crusher rather than shut it down when there is no feed, and of course we generally run the material "in circuit" off the belts and spreader, which might take the entire shutdown time for the shift change. The alternative is a shutdown and sequenced restart, which could delay the crusher operation and cause queuing at the dump pocket, for example. Hence the crushers will tend to have quite high SMU factors.

3. IPCC system throughput

Now that we have assessed the operating hours for the IPCC systems, it remains to determine the annual throughput that can be achieved by the systems.

The system throughput is determined from the following inputs:

a) The instantaneous throughput of the crusher
b) The instantaneous output of the shovel in the case of a FMIPCC system
c) How the shovels are trucked in the case of a SMIPCC system
d) The impacts of the efficiency of the operation (the minutes per hour)

3.1 Instantaneous and average crusher throughput

It is important to know what overall hourly rate of material removal using IPCC is targeted. This is usually derived from analysis of a mining schedule which has been developed for truck/shovel operation and optimisation, but for large operations typically we have a target of between 4500tph and 5500tph average productivity per shovel, which is the start point for both SMIPCC and FMIPCC system design.

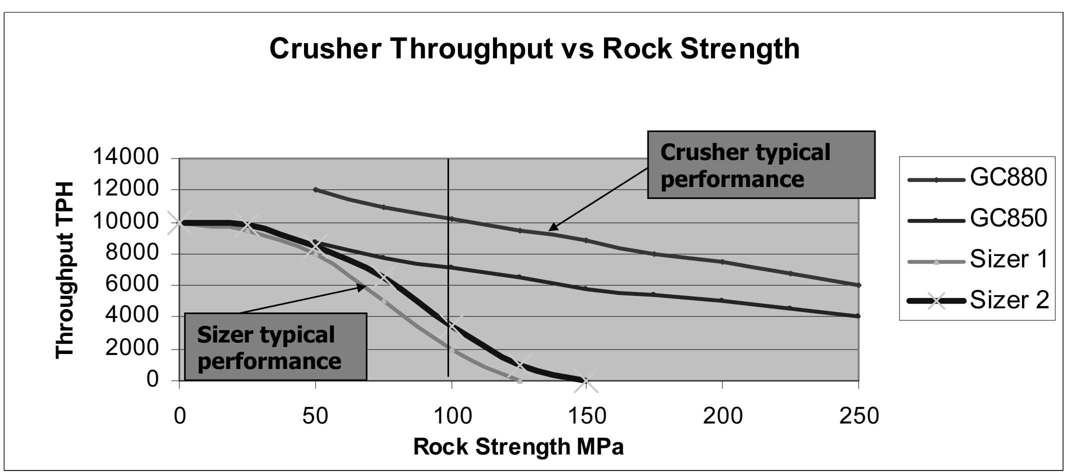
It is not the objective of this paper to discuss the finer points of the mining engineering aspects of IPCC scheduling. A.Cooper of Snowden has covered this topic and the reader is referred to his paper[2]. However, it is necessary to talk here about instantaneous shovel productivity to look at the design capacity for (in particular) a FMIPCC crusher.

3.1.1 Crusher and Sizer/Rolls crusher capacities

The industry manufactures a range of different options for processing of material using in-pit crushers.

Figure 5 shows an example of the current capacities possible. This is only INDICATIVE due to the impact of fragmentation and the intended belt width as well as rock strength on crusher throughput. It does show however the practical limits for different crusher types. Whether a sizer of crusher, generally as a supplier we take the available rock strength, blast fragmentation data and an understanding of the conveyor width likely to be used (which determines the maximum fragment sizes we can handle) and run it through a crusher design package which will provide us with the possible instantaneous and average throughput for a range of sizer or crusher options for the material. Even the largest crushers available generally cannot achieve more than a 10,000tph capacity however, and this is the boundary for current single IPCC systems.

Figure 5 Crusher and Sizer throughput indications



3.1.2 SMIPCC throughput

Figure 6 shows an example of a truck/shovel instantaneous and average production. In this example, when fully trucked we could expect material to be arriving at the crusher station at a rate as high as 6,900tph from each shovel. However, as we have a feed bin to absorb the high instantaneous arrival, we can choose to design the crusher at something closer to the average throughput of perhaps 5400tph.

Figure 6 SMIPCC Shovel productivity - instantaneous vs. average

SHOVEL ANALYSIS MODULE - SMIPCC

Loading Unit =	EX5500			**Truck =**	EH5000		
INSTANTANEOUS				**AVERAGE**			
Loading Unit Rated Capacity	Tonnes	49		Loading Unit Rated Capacity	Tonnes	49	
Nominal Bucket Factor		1.00		Nominal Bucket Factor		1	
Truck Rated Capacity	Tonnes	318		Truck Rated Capacity	Tonnes	318	
Nominal No of Passes	no.	6.49		Nominal No of Passes	no.	6.49	
Mean shovel wait time	mins	0.30		Mean shovel wait time	mins	0.50	
Nominal Load time	mins	2.78		Nominal Load time	mins	2.98	
Queuing Time	mins	1.00		Queuing Time	mins	1.00	
Travel Time - Ore	mins	0.00		Travel Time - Ore	mins	0.00	
Travel Time - Waste	mins	6.00		Travel Time - Waste	mins	6.00	
Waste:Ore Ratio	ratio	1000.00		Waste:Ore Ratio	ratio	1000.00	
Average travel Time	mins	5.99		Average travel Time	mins	5.99	
Effective Minutes per Hour	mins	60.00		Effective Minutes per Hour	mins	50.00	
Cycles per Hour		6.14		Cycles per Hour		5.01	
Truck Productivity per Hour	Tonnes	**1952**		Truck Productivity per Hour	Tonnes	**1594**	
Loading Unit Trucks per Hour	no.	21.59		Loading Unit Trucks per Hour	no.	16.78	
Loading Unit Productivity	tonnes/hr	**6866**		Loading Unit Productivity	tonnes/hr	**5338**	

This allows us to establish that in order to have a good match with fully trucked shovels; we need to think about being able to process multiples of the production level possible for each shovel that will feed the system. Now it is necessary to match this with the crusher analysis referred to in the previous section, and try to obtain the best match possible between the schedule, full utilisation of shovels, and full utilisation of the crusher.

For this example if we needed a high scheduled tonnage we would select the largest possible crusher and determine the throughput, which would exceed one shovel but be reasonably close to the average capacity of two fully trucked shovels. As we find in most mines shovels are deliberately under trucked so as to minimise haulage costs, two shovels is a good match for a nameplate 10,000tph crushing station. If the tonnage was lower we would select a unit at the instantaneous capacity of the single shovel and accept that as the maximum throughput. We would then put more trucks onto our short hauls to get the average throughput up as close as possible to the instantaneous level.

3.1.3 FMIPCC throughput

Figure 7 shows an example of a shovel instantaneous and average production for a FMIPCC system. In this example there is no shovel queuing in an instantaneous situation, and the production assuming 60 minute hour efficiency is correspondingly high at 7700tph. In this case we have the crusher fully committed to the single shovel, so the system production is limited by the effective hour allowing for shovel manoeuvring and the interaction with the crusher as discussed previously. A typical result for a large shovel is +/-5500tph.

Figure 7 FMIPCC Shovel productivity - instantaneous vs. average

SHOVEL ANALYSIS MODULE - FMIPCC

Loading Unit =		EX5500	**Truck =**		EH5000
INSTANTANEOUS			**AVERAGE**		
Loading Unit Rated Capacity	Tonnes	49	Loading Unit Rated Capacity	Tonnes	49
Nominal Bucket Factor		1.00	Nominal Bucket Factor		1.00
Truck Rated Capacity	Tonnes	318	Truck Rated Capacity	Tonnes	318
Nominal No of Passes	no.	6.49	Nominal No of Passes	no.	6.49
Mean shovel wait time	mins	0.00	Mean shovel wait time	mins	0.40
Nominal Load time	mins	2.48	Nominal Load time	mins	2.88
Queuing Time	mins	1.00	Queuing Time	mins	1.00
Effective Minutes per Hour	mins	60.00	Effective Minutes per Hour	mins	50.00
Loading Unit Trucks per Hour	no.	24.20	Loading Unit Trucks per Hour	no.	17.37
Loading Unit Productivity	tonnes/hr	**7697**	Loading Unit Productivity	tonnes/hr	**5523**

4. Annual System capacity

The result of the analysis presented in the previous sections provides a basis for determining the annual throughput of a SMIPCC and FMIPCC system. Figure 8 and Figure 9 show the typical annual throughputs generated for different rock strengths for large SMIPCC and FMIPCC systems.

Figure 8 Annual capacity - nominal 10,000tph SMIPCC systems

SMIPCC Capacity					
10000tph Nominal	**Crusher Type**	**Instant tph**	**Average tph**	**Op Hrs hrs**	**Annual mtpa**
150 MPa	Gyratory	9000	8500	5697	48.42
100 MPa	Gyratory	10000	9500	5697	54.12
50 MPa	Gyratory	10500	10000	5697	56.97
50 MPa	Sizer	8500	8000	5697	45.58
25 Mpa	Sizer	9500	9000	5697	51.27
Clay	Sizer	10000	9500	5697	54.12

Figure 9 Annual capacity - nominal 7,500tph FMIPCC system

FMIPCC Capacity					
7500tph Nominal	**Crusher Type**	**Instant tph**	**Average tph**	**Op Hrs hrs**	**Annual mtpa**
50 MPa	Sizer	6750	5500	5285	29.07
25 Mpa	Sizer	7500	5500	5285	29.07
Clay	Sizer	7500	6000	5285	31.71

Please note that as stated previously the throughputs for crushers or sizers is a function of not only rock strength but fragmentation, conveyor width, and abrasiveness. The numbers above should be used with these considerations in mind, and are provided only as an example.

5. Acknowledgements

The authors wish to thank the various companies that have contributed to finessing the operating data discussed in this paper through the IPCC studies that have been undertaken during the past 12 months. These include Xstrata, BHPBilliton, Anglo American, Kumba Iron Ore and Ridge Mining Ltd.

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