How a focus on equipment performance promises to unlock billions of dollars in productivity returns for miners.

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Mining for efficiency

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Executive summary

Australia's declining productivity is one of the most important challenges for our economy. It calls into question the path to future prosperity and our global competitiveness unlike any other topic. And when it comes to productivity, no industry has received greater attention of late than mining.

With the evolution of new technology and mining methods, combined with projects of ever increasing scale, one might have reasonably expected productivity in the Australian mining sector to have increased over time. But for a range of reasons, at an industry wide level, the reverse has actually been the case.

The popular tagline of the mining sector is that the miners are serious about productivity. We suggest that most are reducing costs and increasing volumes but there are precious few with legitimate claims to improving core productivity in their open cut operations. Miners are banking the first available dividend, selling or segregating mines deemed too hard to fix and tempering expectations of further productivity gains by citing a combination of labour laws, high costs, regulatory hold ups and mine configuration constraints. There is no question that sustainable productivity dividends are harder to achieve, but if tackled properly they will drive superior long term returns.

Many have been quick to point the finger at the overhang created by the volume maximisation strategies that prevailed during the commodity boom years, where absolute output was deliberately prioritised. But understanding why productivity fell during this period, and has continued to fall since, is a complex issue.

In this report we have diagnosed the extent of the productivity challenge at both a macroeconomic and operating level, in Australia and across the other major mining regions. For the latter, we have drawn upon 20 years of operating performance data from 136 mines and 4,760 individual machines – in all, this represents more than 47 million operating hours.

Key findings

- The global mining industry's open cut equipment productivity (ie annual output / capacity of input) has declined by 20% over the past seven years despite a push for increased output and declining market conditions.
- Mining equipment in Australia runs at lower annual outputs than most of its global peers. Australia is not best in class for output from any category of equipment and is below the annual output of North America across all classes of equipment.
- There is an inherent conflict between a productivity plan based on increased volumes and one based on cost reduction. Those mines with well delineated strategies which are followed with discipline by their people make up the majority of those achieving top quartile equipment performance.
- Company-wide equipment performance for many global miners sit in the second and third quartiles, and the differences between their best and worst performing mines are stark (see Figure 5). The differences between median performance and best practice output by equipment category can be over 100% (see Table 2 for differences by class of equipment), the majority of which can't be attributed to different mining conditions or embedded issues associated with existing mine plans. For example, hard rock mining conditions are a well-worn excuse for poor productivity performance, when in fact the data reveals there are many mines digging very hard materials who are achieving best practice. The extent to which these variances are monitored, rationalised or dismissed is unclear as data capture management practices are still evolving compared with many other industries. The Tier 1 assets have the best ore bodies in the world. Imagine how profitable they would be if they also delivered best in class productivity performance.
- Productivity is heavily dependent on the way people act. A better rated piece of equipment might deliver 5-10% output improvement, and require additional capital, but changes in the work practices can, in our experience, deliver 20%+ gains, often at little or no cost. Again, industrial relations issues are perceived as the primary constraint to productivity, yet the data shows significant divergences in performance from mines operating in close proximity, chasing the same commodity, and under very similar IR conditions.

Implications

- Mining companies understand implicitly that productivity carries a value, but are not armed with the right data to make informed choices on the risks/rewards involved. Costs deferred or eliminated, as well as volume increases, have become the proxy for productivity gains. What's more, in the current environment there is little patience for a productivity dividend that might be six or twelve months in the making, let alone one that needs an outlay of substantial capital to get there.
- Sizing the productivity prize will vary for each mine. To give some sense of the magnitude of the upside we considered the gains that could be made for a single item of equipment moving from median to best practice annual output, and then applied a conservative cost per tonne (representing the marginal cost of having that incremental material being moved by some other method, by an additional loader, truck, excavator, etc) – refer Table 3. As an example, a front end loader of average bucket capacity that could shift from median to best practice would increase annual output by 6.1 million tonnes and generate cost savings of between $1.50-2.00 per tonne. (ie a return of $9 – 12 million per annum per machine). Best practice may not be possible on all sites, but apply this benefit to a substantial portion of a miners fleet and the financial upside quickly mounts.
- Benchmarking of equipment performance has generated significant gains in some quarters and served to highlight diminished performance for others. On page 13 we provide brief case studies from mines across the globe.
- In our view the easiest gains can be made in the areas of payload and availability. Annual performance is more highly leveraged to payload than any other metric, yet this is often overlooked. Maintenance practices can make the difference between equipment achieving typical availability rates of 85% and those achieving best practice of 90% or more. Again, some examples are included on page 13.

The implications for improving productivity in the Australian mining sector are clear. Companies serious about both cost control and productivity need to have a greater focus on the efficiency of their equipment. This means stepping beyond short term cost reduction initiatives and a preoccupation with extra tonnes leaving the mines. It's about what's happening inside the gates that is the key to arresting the industry's productivity decline.

The productivity doldrums

Understanding why productivity fell following the commodity boom is a complex issue. There are a range of impacts arising from the increasing scale of open cut mines and complexity of mining operations, which may at first glance seem counter-intuitive. For example:

- Performance actually decreased as equipment capacity increased for draglines, hydraulic excavators and front end loaders (see Figures 10, 20 & 25 in the Appendix).
- For some equipment manufacturers new, larger models have not produced immediate, proportional improvements. For example, OEM 1 in Figure 29 of the Appendix, produces decreasing unit performance as the models get larger.
- During the boom years some mines were forced to acquire equipment which was available rather than what they really needed and at the same time due to talent shortages recruited relatively less skilled labour to operate it.

The recent downturn in commodity prices in particular has now led mining companies to take strong steps to improve productivity. Many have stated publicly that productivity is top of their agenda and they are extolling the virtues of cuts to employee numbers and spending.

But is productivity actually improving? The short answer is that it depends on what measure you use. This report looks at a number of publicly available macro performance measures typically used to describe productivity in the mining sector. We need to recognise that these measures are not based on an understanding of how individual mines perform at an operational level. While they help identify and support underlying trends, they cannot provide the detail required to make optimised strategic decisions and comparisons with other mining nations are difficult.

A more detailed understanding of productivity in mining based on operational-level has been made possible by data collected by PwC's Mining Intelligence & Benchmarking practice[1]. Our database is the leading source of information about the productivity and reliability of open cut mining equipment in the world.

The database constitutes performance data sourced directly from equipment monitoring systems over a period of 20 years. The data covers five continents and 136 mines. It includes 308 different makes and models with over 4,670 individual machines and more than 12,000 years of operating data. Those machines have more than 47 million operating hours and more than 700 million cycles.

The approach that has been developed within the database seeks first to normalize for a range of factors outside the mine's control (including commodity being mined, what is being dug, location - including weather, pit geometry and make and model of the equipment) and then measures best performance. This determines an optimum performance level against which variances can be measured for that particular mine.

Drawing on this database, PwC has developed a number of metrics that allow companies to better understand the operational-level drivers of productivity. For example, PwC has developed the Mining Equipment Productivity Index (MEPI), which provides a more precise estimate of the productivity of mining operations by measuring the physical output of the mine equipment.

Our operational-level analysis has revealed that:

- The global mining industry's open cut equipment productivity has declined by around 20% over the past seven years despite a push for increased output (see Figure 3 of the main report)
- Australian mining equipment appears to be run at a significantly lower level of annual output compared to most other mining countries (see Figure 4 of the main report)
- There does not appear to have been effective or significant change in operational mining strategy during this time, despite changes in commodity prices.

This last point was particularly evident during 2011 – 2013 where a number of commodities declined in price significantly (for example, coal and gold) but a detailed examination of mining productivity data from mines with those commodities revealed a lack of change in mine site strategy, despite what the miners may have stated publically.

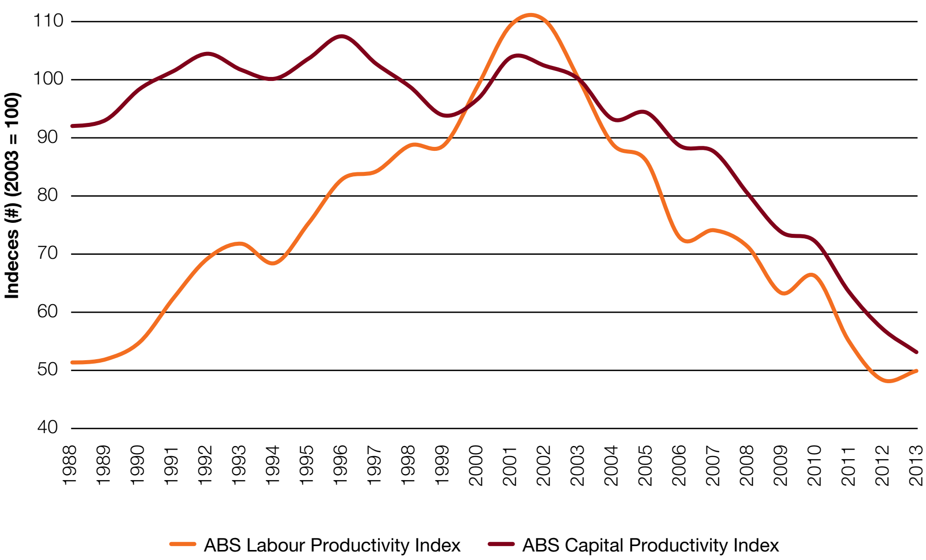
[1] Formerly GBI Mining Intelligence, which was acquired by PwC in September 2013

What the macro measures reveal

Mining productivity is typically described by reference to publicly available data from the Australian Bureau of Statistics (ABS), the Reserve Bank of Australia (RBA) and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES).

The publicly available data is largely focused on labour, capital, capacity and output. Whilst important for monitoring industry-wide trends these metrics do not provide sufficient understanding of what's happening at the operational level to enable executives to make changes to their strategies that will maximise productivity. Furthermore, the metrics do not appear to support the recent productivity claims of mining companies, which argue that following reductions in headcount and spending they are now 'doing more with less'. The following sections explain why.

Figure 1: Labour and Capital Productivity (Source: ABS)



ABS labour and capital productivity indices

If productivity in the mining sector were simply about the deployment of labour and capital, then we would expect to see the headcount and cost reduction strategies recently adopted by the miners leading to a demonstrable improvement in productivity. But it's simply not the case.

An analysis of the ABS's Labour and Capital Productivity Indices reveals only limited gains of late (see Figure 1). The Labour Productivity Index in 2013 was just 3.2 per cent higher than 2012. This is less than the minor corrections that occurred in 2006-07 and 2009-10 and may be just 'noise' in an otherwise downward trend. Capital Productivity has fared even worse, with no substantive increase since 2001.

In previous analysis we have released on mining productivity it was clear that austerity approaches have largely failed to deliver improved productivity[2]. For example, despite widespread reports of redundancies and operational headcount reductions in the mining industry in 2013, Labour Productivity has only risen 3.2 per cent. And even though the capacity of new equipment being commissioned decreased 44 per cent in 2013 compared with 2012 (Parker Bay Mining), the Capital Productivity Index still fell by 7 per cent.

PwC maintain that while labour and capital should be important aspects of analysis regarding the financial sustainability of the mining industry, they should not necessarily be the primary focus for understanding or improving mining productivity.

[2] Productivity not austerity: Productivity scorecard – mining focus, PwC, 2013

Capacity and output metrics

The decline in labour and capital productivity in the mining industry since 2001 has been broadly attributed to companies making a shift from a cost conscious strategy in the 1990's (minimising marginal costs and accepting lower output volumes) to a volume strategy from the mid 2000's (achieving the maximum output despite increasing marginal costs) in order to capitalise on the boom in commodity prices. But a deeper analysis reveals that the causes of decreasing performance are not so simple.

As commodity prices rose over the past decade, so did the mining industry's investment in capacity, which has also been well above the long-term trend. Figure 2 shows that from 2003 to 2012 the Australian mining industry annual investment in new earthmoving equipment capacity[3] increased by 17 per cent, on average.

Production output[4] data indicates that the industry was not, however, able to effectively capture the opportunity high commodity prices presented.

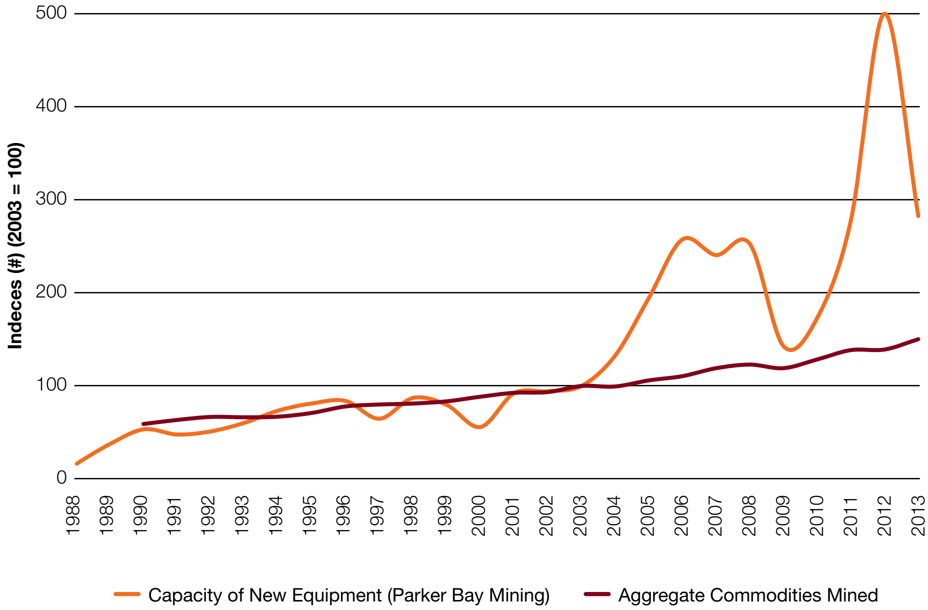
During the same 2003 to 2012 period the aggregate commodities actually mined grew by an annual average of 5 per cent a year, just a small amount ahead of the industry's longer-term increase of 4.2 per cent.

Presuming a consistent split of open cut and underground mining over the 10-year period, the total increased capacity acquired has been nearly eight times the aggregate amount of additional commodities sold from these mines. Productivity, therefore, has gone down as the rise in inputs is greater than the rise in outputs. Clearly, attempting to exploit high commodity prices has cost mining companies dearly.

Understanding the reasons for the gap between investment and output (from Figure 2) is critical to improving Australian mining productivity.

PwC data reveals that the main reason for this discrepancy is that most of the productivity issues are operational.

Figure 2: New Australian Mining Equipment Capacity (Source: Parker Bay Mining) and Aggregate Australian Mining Output (Source: RBA) 1988-2013



[3] Source: Parker Bay Mining
[4] Source: RBA

What operational-level data reveals about productivity

Productivity across the industry: MEPI

Because understanding what's happening at the operational level is so crucial, operational-level data is the key to improving productivity in the Australian mining sector. To this end, PwC has developed the Open Cut Mining Equipment Productivity Index (MEPI).

The MEPI measures the efficiency of open cut mining operations by comparing how much material mining equipment is moving from one period to the next. It draws on performance data from a combination of equipment: dragline, rope shovel, hydraulic excavator, front end loader and truck performance, and is based on PwC's proprietary mining equipment productivity and reliability database.

PwC's MEPI supports the claim that the efficiency of mining equipment across the sector is in decline. Equipment operating efficiency reached a peak in 2006, and has decreased ever since (Figure 3). In 2013 it was 18 per cent lower than for 2006.

On a regional basis (Figure 4) mining equipment performance has been declining at different rates across all mining jurisdictions. Australia's mining equipment productivity underperforms our international competitors with the exception of Africa[5].

Figure 3: PwC's Aggregate Mining Equipment Productivity Index (2003 = 100) (Source: PwC's Equipment Productivity and Reliability Database)

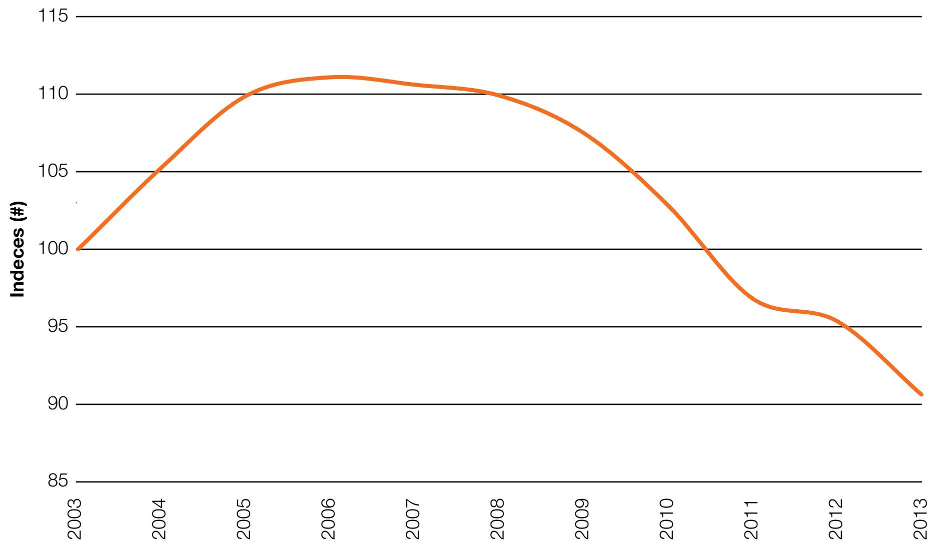
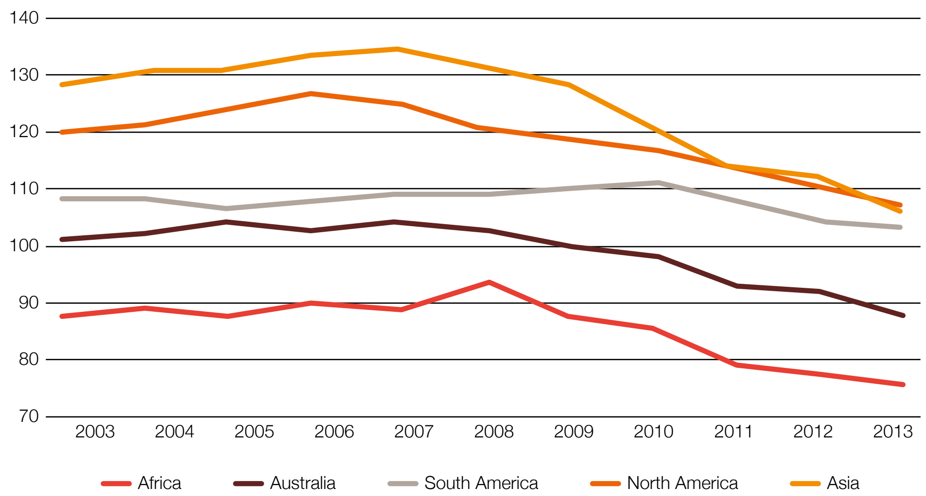


Figure 4: PwC's Mining Equipment Productivity Index by Region (Source: PwC's Equipment Productivity and Reliability Database)



[5] The issue about Australia's relative position in the global mining industry is a substantial topic and is beyond the scope of this paper. Australia's position is a function of work practices, culture, leadership, strategy, etc. and not simply a function of poorer equipment or the environment. This is an issue that needs to be taken up and studied in more detail.

It is important to distinguish the declines represented in Figure 3 and Figure 4 from any suggestion of structural shift in the industry due to non-controllable factors (eg. increased emphasis on safety, more difficult mining conditions, changes in labour laws, increased government regulations, etc). As Figure 3A shows, although median performance has declined since 2006, the gap between median and best practice, what we regard as the total productivity opportunity, has grown.

Productivity of different types of mining equipment

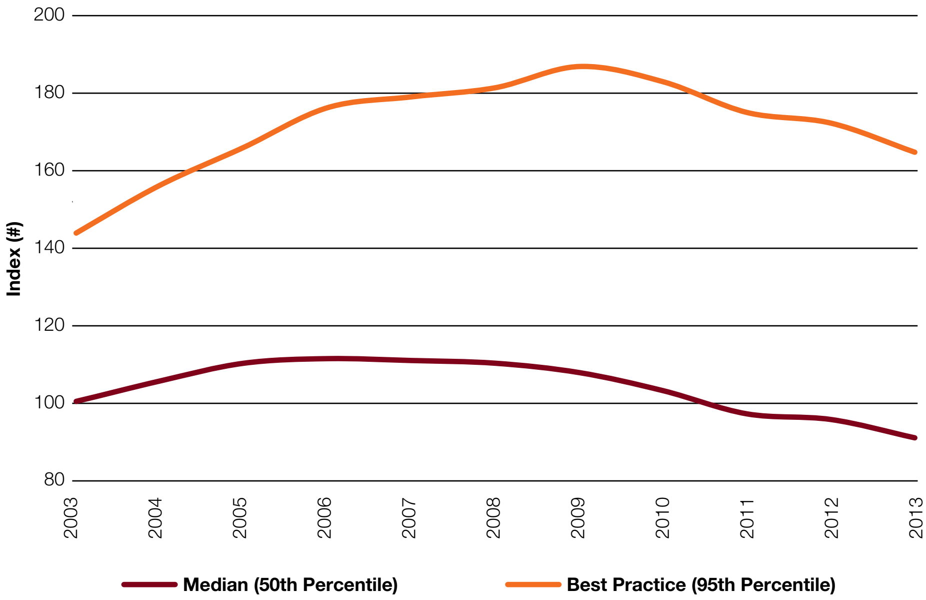
Equipment-level data drawn from our database also reveals the performance of individual classes of equipment over the past 10 years, including draglines, rope shovels, excavators, front end loaders and trucks. A detailed breakdown of performance data for the different classes of open-cut mining equipment is included in the Appendix. Following is a brief outline of the key insights from that analysis.

The median productivity of all classes of equipment across all mining jurisdictions and commodities has fallen since 2006 (see Table 1 below). There are, however, significant differences in performance between different countries.

Table 1: Reduction in median productivity of equipment in 2013 since the 2006 peak (Source: PwC's Equipment Productivity and Reliability Database)

Dragline	-20%
Electric Rope Shovel	-21%
Hydraulic Excavator	-14%
Front End Loader	-23%
Mining (Haul) Trucks	-32%

Figure 3A: PwC's Mining Equipment Productivity Index - Median vs Best Practice (Source: PwC's Equipment Productivity and Reliability Database)



These falls reveal an enormous opportunity cost associated with the loss in material movement across the industry worldwide. It should also be noted that best practice has fallen by less than median. The reasons for this seem obvious. One characteristic of best practice is that these mines continually focus on what they have to do to not only maintain performance, but to keep improving. That same focus and drive is not evident across a large percentage of the industry.

Interestingly, Australia is not best-in-class for output *from any* category of equipment and is below the annual output of North America across all classes of equipment. Australian annual output relative to Asia, South America and Africa is also generally lower.

The difference between best practice and median is also wide in all classes of open cut equipment (See Table 2).

Table 2: Best practice equipment output gain versus median output, 2013 (Source: PwC's Equipment Productivity and Reliability Database)

Dragline	56%
Electric Rope Shovel	64%
Hydraulic Excavator	85%
Front End Loader	156%
Mining (Haul) Trucks	82%

It is proposed this represents the potential gain for the median machine in each class. Whilst no two mines are the same, our experience, supported by extensive operational data, provides few reasons why most equipment cannot achieve close to best practice levels of performance.

Productivity of global mining companies

Figure 5 below plots the equipment performance of ten large mining companies, showing the best, worst and average performing mines within their portfolios. Companies names are necessarily removed, but it is worth noting that most were included in our recent global Mine 2014 report covering the largest 40 miners by market capitalisation.[6]

The analysis reveals some telling comparisons with how the market is viewing productivity performance and how it is being portrayed within the industry. For example:

- Many of those represented in the chart have poor performing mines within their portfolios, but these aren't necessarily the ones identified as marginal or underperforming in their operating or financial reports. Similarly, some commodity groups or specific operations heralded as high achievers on a broader productivity scorecard have relatively low equipment efficiency.
- There is a high correlation between some of the poorest performers in the table and those with a poor financial and share price performance in the past 12-24 months
- There are significant divergences in the locations of better and worse performing mines. Some miners have their best performers in South America, others have their poorer performers in that region. Similarly, for those with operations in Australia, we can identify best in class for some miners and worst for others.
- Some of the most productive mines are those that have been offloaded in the past by the majors. It could be argued that some of these have to be productive, and are often raising the bar on best practice, because they operate on very slim margins. Productivity improvement is necessary to survive.
- Some miners who have announced productivity improvements have focused their benchmarking on internal comparisons and as a result are found outside top quartile performance across the industry.

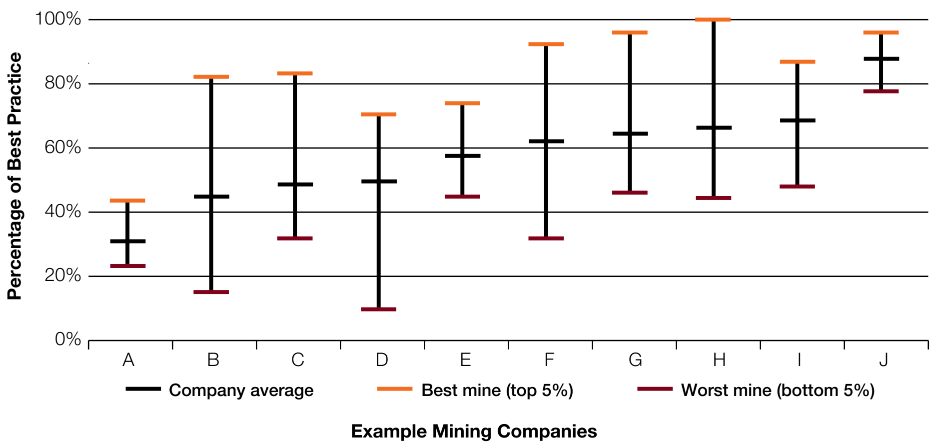
Sizing the prize

Table 3 below outlines the potential gain in MT per annum by equipment class from moving from the median performance to best practice for each class of equipment. Using a conservative cost model, each of the tonnes "lost" costs a mine between A$1.50 and A$2.00 (which is the cost of having to move those tonnes with another truck and loader fleet) except in the case of a dragline, where the cost is around $0.50 per tonne. Once you start factoring in the size of a fleet and the number of mines in a portfolio, even capturing a small portion of this upside will quickly amount to a prize measured in tens of millions of dollars per annum.

Table 3: Best practice equipment output gain versus median output, MT per annum, 2013 (Source: PwC's Equipment Productivity and Reliability Database)

Dragline	18.4
Electric Rope Shovel	11.9
Hydraulic Excavator	11.4
Front End Loader	6.1
Mining (Haul) Trucks	1.6

Figure 5: Mining Equipment Performance by Selected Large Mining Company (Source: PwC's Equipment Productivity and Reliability Database)



[6] Mine: Realigning expectations, PwC, June 2014

Assessing mining strategy effectiveness

One of the key benefits of using equipment-level data is the ability to assess the effectiveness of a mining strategy. This can be done across the industry, or for an individual mine.

As previously noted, mining companies tend to adopt to varying degrees, one of two broad business strategies: a volume strategy (achieving the maximum output despite increasing marginal costs); or a cost strategy (minimising marginal costs and accepting optimised output volumes).

When implemented effectively, these strategies follow a typical pattern of equipment use. Under a volume strategy, an increase in loader output and a decrease in truck output usually occur. This is because companies will invest in more trucks to ensure there is no idle time at the loader. One consequence, however, is that trucks are often sitting idle waiting for their turn to be loaded.

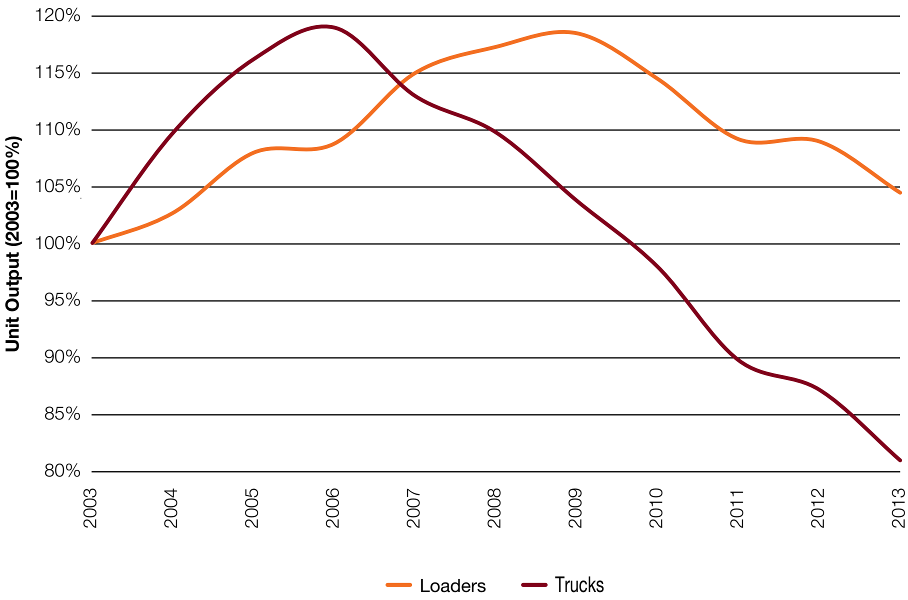
Under a cost strategy the opposite is the case. A high focus on costs generally means fewer, and therefore more highly utilised trucks, while it's the loaders that often sit idle waiting for them.

Our analysis of equipment productivity shows that overall the industry has not been very effective in the adoption of either a volume strategy or a cost strategy.

During periods of high commodity prices, such as occurred over the past decade, many mining companies sought to adopt a volume strategy. An effective uptake of the volume strategy during the 2003–2011 boom would logically have seen loader performance increase and truck performance decline during this time. This was not the case however, with both truck and loader performance increasing and then decreasing over the decade (Figure 6).

Although loader performance did improve through to 2009 the falls in 2010 and 2011 were not expected from an industry attempting to maximise output. The fact that both loaders and trucks increased from 2003 to 2006 is likely more a function of the take-up of underutilised capacity resulting from the previous period of lower commodity prices rather than a demonstration of an effective volume strategy.

Figure 6: Open Pit Loader and Truck Performance, 2003-2013 (2003 = 100%) (Source: PwC's Equipment Productivity and Reliability Database)



The efficient execution of a cost strategy after the 2003–2011 boom would have seen individual truck performance increase (as numbers were optimize to minimise unit cost) and loader performance level off or even decline. The fact both loader performance and truck output declined during this time, however, creates doubt that it was a strategy-related result.

Our interpretation of Figure 5 is that the industry's strategic response to market conditions over the past decade was not optimally effective, for the following reasons:

- Truck output rose from 2003 to 2006 – the effective execution of a volume strategy during a boom would typically see more trucks used with individual truck output falling.
- Loader output declined from 2009 to 2011 – the effective execution of a volume strategy during a boom would typically see more trucks used with loader output increasing.
- Truck output declined from 2011 to 2013 – an effective execution of a cost strategy during a bust would typically see fewer trucks used with individual truck output increasing.

Furthermore, when Figure 2 is considered, it can be seen that the industry predominantly responds to commodity prices when investing (or not) in new capacity, with apparently little focus on the best strategic approach for existing capacity.

In summary, analysing productivity at the equipment level casts doubt on whether the industry has responded well to changing economic circumstances at any time during the past 10 years.

How to improve operational productivity at a mine-site level

Based on our experience and data-driven insights, we have identified three key factors that miners should address to improve equipment efficiency and in turn improve productivity.

Our analysis suggests that three key factors (see graphic right) have the largest impact on mining execution and success and should be top priorities for all mining executives and general managers.

Mine Strategy

As the equipment performance data shows mine strategy was not necessarily optimised for economic and market conditions, even when a strong financial imperative to do so existed.

This was especially true during commodity price downturns, where mine managers often requested across the board cost reductions, which often conflicted with asset optimisation. These directives tended to lead to reduced mine performance.

On the other hand, mines that had clear cost or volume strategies often articulated equipment-specific targets that led to significantly better performance during both boom and bust periods. PwC's own data and experience with mining companies indicated that mines with well-articulated strategies represented more than 80 per cent of companies achieving top quartile loader performance (volume strategy) and 80 per cent of companies achieving top quartile truck performance (cost strategy).

Key factors for mining productivity execution and success

Mine strategy: define, plan, articulate and execute a clear mine strategy, including expectations for specific equipment productivity and removing impediments.

Data management system: develop an equipment-level performance data management process and use it to steer daily decision-making.

People: identify and recruit people with the right "abilities" (what one is born with) for each job; then provide proficiency-based training to all levels within the mine

Developing a clear mine strategy is technically easy. However, translating a volume or cost strategy into clear equipment performance metrics is often difficult due to the complexity of interlinking processes on the mine site. The challenge should not be underestimated.

Additionally, communicating with senior management and operators about equipment performance trade-offs and gaining approval for targeted equipment performance reductions when the established mantra has been "productivity above all" can be daunting for even the most seasoned mine veterans.

Data Management System

Many industries have embraced the use of data to drive decision-making and rely on methodologies like TQM and Six Sigma to bring about step-changes in performance improvement. The mining industry, however, has embraced the 'data acquisition' stage, but is yet to embark on the 'data use' stage of performance management in a significant manner.

Data overload has caused many managers to question whether data can help them make better decisions. Many mines simply do not use data and information that could potentially lead to significant productivity improvements.

A number of miners say they review performance data on a monthly or quarterly basis but don't trust it for decision-making. Others, however, embrace internal and external comparisons to support business improvement as well as the analytic approach to management. On the whole their mines are well rewarded. Mining companies that gather, analyse and use their data on a daily basis account for 92% of top-quartile equipment performance.

The use of available data is a proven distinguishing feature of mines that achieve outstanding equipment performance. Measurement and data-management systems should be in place to accurately and consistently record all key performance indicators, including productivity, time management, fleet management and safety issues for all mining equipment.

As a minimum, payload should be recorded for every cycle plus load and time-based events in the cycle. Problem actions, (such as speeding trucks in corners, shovels digging incorrect R.L's, under or over trucking, etc.) should be identified and recorded. The database structure should be documented and available. Internal and external benchmarking should be undertaken regularly. Tailored analytic methods and reports should be developed and then incorporated into a process of data-based management. Best practice mines often have a 'data steward', someone whose responsibility it is to collect and store this kind of data.

People

The full potential of a clear mine strategy and sound data management systems will not be achieved if the mining company lacks the right people and skills.

Selecting the right people, particularly at the operational level can lead to higher productivity. Research in Human Factors Engineering has found that accounting for individual differences during selection and recruitment can increase equipment output by up to 14 per cent.

Mining companies need to recognise the role of both people selection and proper training of those people. The importance of selection is particularly salient considering the fact that over the past 20 years average operator performance has declined. In 2007 it was 9 per cent below the performance achieved in 1993[7], and from our recent experience we believe that the situation has not improved. While the precise cause of this decrease is not clear, it is known that the natural abilities of operators (those related to productive operation of large earthmoving equipment) are approximately 10 per cent lower now than 20 years ago. That means selection of operators is being done less efficiently now. Of concern here is the fact that the previously dominant system of selection by seniority has been replaced with a system where mines may choose the people they want.

The process of training to initially achieve competency and eventually proficiency in any given task requires constant attention and it is apparent from the data that the required attention has waned. It is known that the skills acquired through training and experience are 3 to 4 per cent lower (relative to what they are capable of) now than they were 20 years ago.

Finally, it's important to recognise that these three factors – strategy, data and people – must be considered as an integrated whole. Mines achieve exceptional performance when they value the experience of their people and attempt to contextualise this experience with data-derived knowledge and a clear mine strategy.

[7] Lumley G 2007, Improving Dragline Operator Selection And Support Processes, University of the Sunshine Coast, Thesis submitted for the degree Doctor of Business Administration.

Case studies

We have summarised below examples of successful turnarounds where equipment benchmarking drove operational changes which in turn paid a handsome dividend. On the other side of the coin, we summarise situations where underlying flaws in the approach to benchmarking hampered progress.

Successful outcomes

1. A mine with multiple loading units and trucks benchmarked the equipment against the performance of similar makes and models. In response this mine immediately started working on their utilisation to address large gaps between their performance and best practice in operational standby time; especially under "No work available" and "No operator". Their actions were targeted around having the optimum number of trucks allocated to each loader. Further, they established a more flexible approach to which trucks reported to each loader. After three months the mine reported improvements in individual loader and truck utilisation (of up to 10%) which they estimated added $40M to their annual operating profit.
2. A coal mine had a 550 tonne class excavator. Over three years they had doubled annual output from 7 MT to 14 MT and subsequently undertook a benchmark against worldwide performance. They were stunned to find they were still 32% below best practice. The most significant gap between what they were doing and best practice machines was payload. In the following two years they improved output by simply bringing focus on to payload – everyone in the truck and loader operations was charged with reviewing all activities to give priority to filling every load (loader and trucks). This had the flow-on effect of improving their truck and loader matches so that fewer trucks were sent away from the loader not full, and there were less loader part loads putting the last tonnes in the truck. They subsequently achieved the equivalent of best practice performance.
3. An Australian dragline was very low in output. The mine developed a program of improvement activities such as optimised selection of new buckets, increasing target suspended load, improved diggability from blasting, improved availability and utilisation, changing their input layout, and they changed some of their operators; all which was assessed against quarterly benchmarking. They targeted a 5% improvement every quarter which they achieved in eight successive quarters.
4. An Australian dragline was very high in output for every year for five years in a row. They still increased output by 1-4%, despite the fact that they were at or above the 95th percentile each year. They looked at the gap between their KPI's and the best practice group and focused on areas where they were below. They pushed the dragline to load past the manufacturer's stated load (while putting suitable controls in place); they reduced bucket and rigging weight and converted it into payload; and they increased their production time. Their simple aim was to be the best dragline in the mining company's fleet and they achieved this goal.

Why benchmarking alone is not the solution

1. A gold mine was being developed. A benchmark was identified within their mine planning assumptions that required two large rope shovels to have usage rates equivalent to the 95th percentile. For the first few years the mine failed to meet production targets and failed to use the data from the benchmark to improve. The shovels have never achieved the rates used in planning. They have now achieved target total mine output through the acquisition of additional capacity (which came at additional cost). The basis for the company's reserves statement and the feasibility studies were subsequently called into question. This mine has never returned the projected ROI.
2. A number of mines which have conducted benchmarks of their open cut equipment have failed to act on the recommendations. When the benchmark is repeated, a remarkably similar result is identified which, without intervention, tends to decline slowly over time. For example, a large coal mine was part of a company-wide benchmarking exercise which was repeated annually for 9 years. At the end of the 9 years the mine's equipment performance was more than 10% below what it was at the start. For this mine the main issue was falling production hours. Availability was constant but non-operating activities increased and as a result utilisation fell.

Appendix: Trends in performance of open cut mining equipment

This Appendix, which is based on data collected by PwC's Mining Intelligence & Benchmarking service[8], provides a detailed analysis of the performance of different categories of open-cut mining equipment up to and including 2013:

- Draglines
- Electric rope shovels
- Hydraulic Excavators (face shovels and backhoes)
- Front end loaders (wheel loaders)
- Mining haul trucks

It is a rewritten and updated version of the 2012 paper by GBI Mining. Some of the results are different to this previous paper due to additional units available in the data now as well as some enhancements to comparative techniques. The following points need to be understood prior to analysing the results.

- Methods and metrics are used which allow comparisons amongst a number of operations.
- The data which PwC can provide in this document is limited by the data which is in PwC's Equipment Productivity and Reliability Database. Where possible, PwC have classified all data to the PwC Standard Time Usage Model however such detail was not always possible to represent. For example, not all mines will record all activities down to details such as shift change etc.
- All data in the PwC Database was obtained from third parties. PwC has not verified, validated or audited any of the data in the PwC Database and makes no representations or warranties regarding its accuracy or completeness or its suitability for any purpose. PwC is not liable to any party, for any inaccuracy or error in, or omission from, any information in this document or on which this document is based, regardless of the cause of the inaccuracy, error or omission.
- The data in this document was based on available data in the PwC Database as at the date of analysis.

This analysis has made no effort to define what equipment was doing during the available time. For example, some fleets may be doing clean-up while others are doing production work. When issues of what a piece of equipment was doing are impacting performance a further question is then posed. "Are the particular activities in question the best asset allocation and use of capital for this mine?"

Definition of 'Median' and 'Best Practice'

Median means, for each individual production or time utilisation KPI, denoting or relating to a value or quantity lying at the midpoint of a frequency distribution of measured values, such that there is an equal probability of falling above or below it. Median can also be described as the 50th percentile.

Best Practice means, for each individual production or time utilisation KPI, the average for that KPI calculated from the top 10% of machine years (as defined below) for loading units in an agreed benchmark population when ranked by total annual output. Best practice will be close to the 95th percentile but is not necessarily exactly equal to the 95th percentile. That is, the machine years for loading units in the agreed benchmark population are ranked by total annual output, the top 10% of machine years are selected and separated out and the average of each individual production KPI and time utilisation KPIs calculated for the selected machine years only.

Important note: A particular production or time utilisation KPI, calculated as the average of that KPI recorded by the top 10% of machine years for loading units in an agreed benchmark population when ranked by total annual output, may be lower than what is achieved for the same KPI when considered in isolation. There is no machine in the PwC Database which achieves the best result in each individual KPI. Further, a number of KPIs in combination are counter-productive. For example, best practice filling times (lower is better) rarely provide best practice payloads (larger is better).

[8] Formerly GBI Mining, which was acquired by PwC in September 2013

Draglines

The analysis of draglines used annual output in bank cubic metres (BCM) (normalised for full year operation) per tonne of rated suspended load (RSL). A bank cubic metre is the load in tonnes (as weighed by a monitor) divided by the in-situ specific gravity (tonnes per cubic metre). The RSL is a number which the manufacturer places on the machine as being a safe working load.

Figure 7 presents the trends in median and best practice annual output for worldwide draglines from 1994-2010.

The peak productivity for draglines occurred in 2004 at around 127 000 BCM per tonne of RSL for best practice and 98 000 BCM/t for the median dragline. Best practice and median performance declined 14% and 10% from 2004 to 2010 respectively. Since 2010 the median has declined to 20% below 2004 while best practice has recovered to be only 4% below 2004. The difference between median and best practice was reasonably consistent up to 2009 with best practice being between 30% and 32% higher than the median. Since 2009 this difference has grown to 56%.

Figure 8 is a plot showing the differences between median Australian dragline performance and that in South Africa and North America (USA and Canada). These are the three predominant areas where large walking draglines are used. Draglines have been employed in Northern Africa, India and Europe but these have not been included due to lack of data and the generally smaller capacity.

Similar trends can be seen in each area as are seen worldwide. There has been a peak between 2003 and 2005 with a subsequent decline. The decline is particularly evident in Africa (-27%) and Australia (-23%). The decline has been less severe in North America (-5%) and has shown a change in trend in the last three years.

Figure 7: Worldwide Dragline Annual Unit Production (BCM/t of RSL) 1994-2013 by Performance

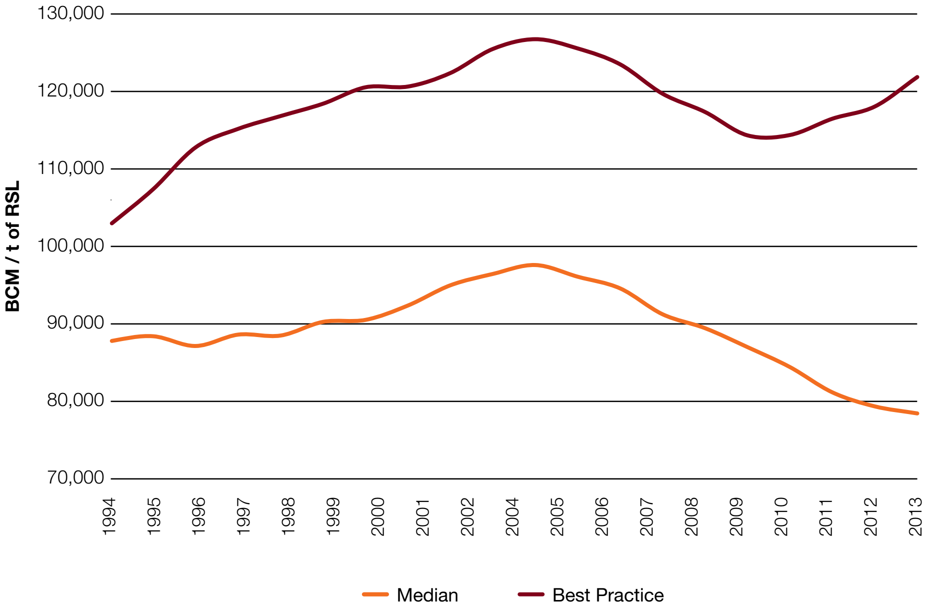
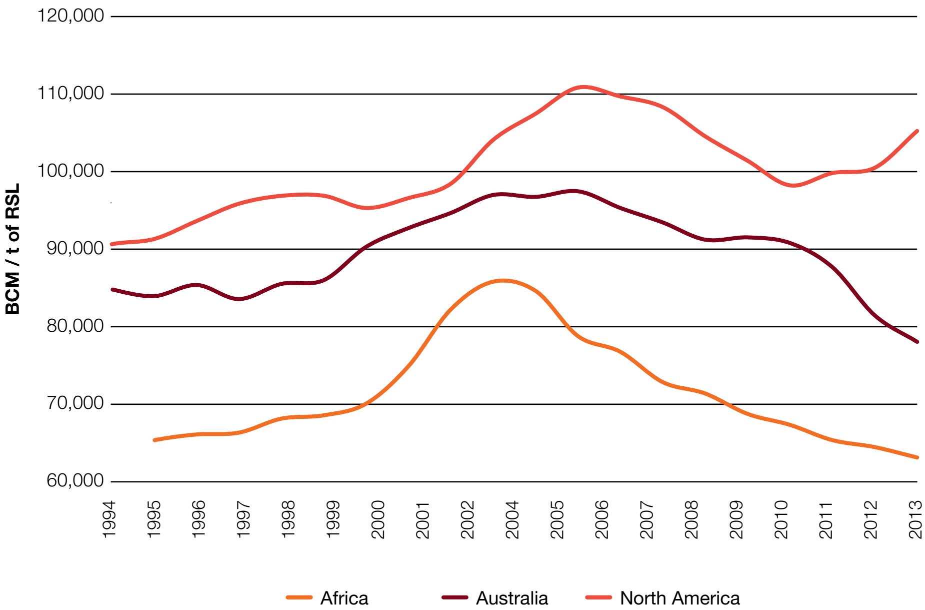


Figure 8: Median Dragline Annual Unit Production (BCM/t of RSL) 1994-2013 by Location



The final comparison is by make and model. Figure 9 shows the 2009-2013 median performance for each make and model.

Each make and model has declined over time but the primary message in this plot is the significant differences between different makes and models. The most productive make and model achieved 106,000 BCM / t of RSL while the least productive achieved 66,000 BCM / t of RSL. The lowest is 38% below the top.

There is an interesting characteristic of this data which is worth noting and plotting in a different form. The unit capacity increases with increasing machine size. In the case of draglines this is not a strong trend but it is gaining strength with time as larger draglines have tended to perform better relative to smaller draglines over the last three years. This is demonstrated in the plot in Figure 10 which is Output versus RSL. Bigger machines move more than smaller machines even after the results are modified to normalise differences in the RSL. The correlation is good although even with an R2 of 0.89 the difference between machines of similar RSL can be millions of BCM per year. By way of example, the two makes and models with RSL around 250 tonnes achieved 26.7 MBCM and 20.2 MBCM per year. The 6.5 MBCM difference in material carries a significant value.

Figure 9: Dragline Annual Unit Production (BCM/t of RSL) 2012 by Make and Model

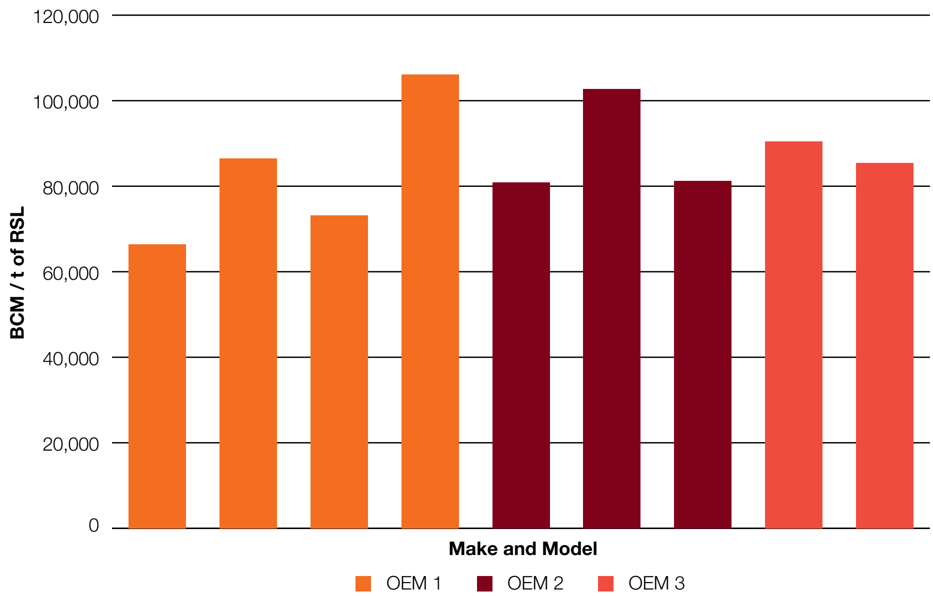
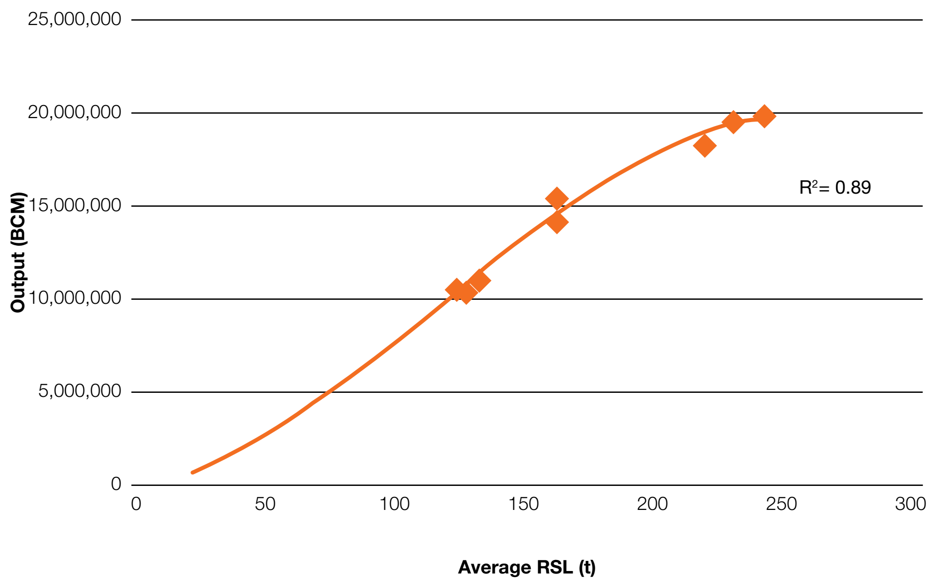


Figure 10: Dragline 2012 Output Versus RSL by Make and Model



Bigger machines move more than smaller machines even after the results are modified to normalise differences in the RSL.

Electric Rope Shovels

The performance of rope shovels in this paper is based on annual output in tonnes (normalised for full year operation) per cubic metre of bucket/dipper capacity. There is divergence between reporting of shovel performance in coal mines and hard rock mines. Coal mines generally report in volume (bank cubic metres or bank cubic yards) while non-coal mines generally report in weight (tonnes or tons). In this paper performance of electric rope shovels has been presented in tonnes to allow consistency between all loaders putting their load in trucks . Further to this the rating of the shovel is in CuM of bucket capacity. All shovels have a rated suspended load but this is not well understood (and can be difficult to find out for some models). It is felt a more meaningful measure of a unit of input for a shovel is the dipper (bucket) capacity. There is some inconsistency between how a rope shovel bucket capacity is defined and the way excavators and Front End Loader's (FEL's) are defined, however this does not detract from the message contained in the data.

As of 30 September 2013, 1,712 large electric rope shovels were operating worldwide (Parker Bay Mining). In 2013 they will move around 28.3 Billion tonnes or 32% of total material movement.

Figure 11 presents the trends in median and best practice annual output for worldwide electric rope shovels from 2004-2013.

The 2004 - 2013 trend for median shovel output is down as it was for draglines. The decline in median shovel output (21%) has been less than the decline for best practice output (30%). The difference between median and best practice reduced from 92% in 2004 to 64% in 2013.

Figure 12 is a plot showing the differences in rope shovel performance amongst Australia, South Africa, North America and South America.

Figure 11: Worldwide Rope Shovel Annual Unit Production (t/CuM of Capacity) 2004-2013 by Performance

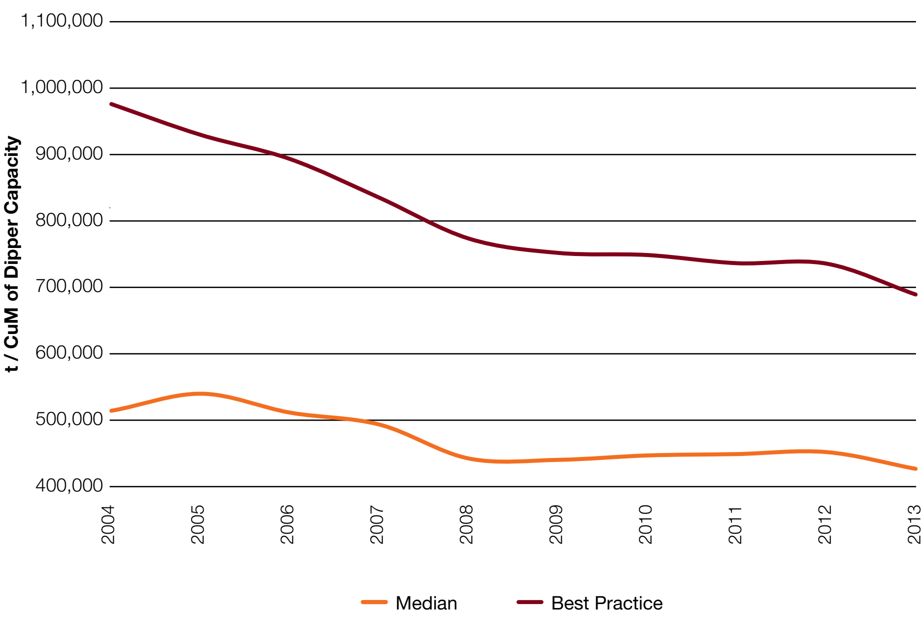
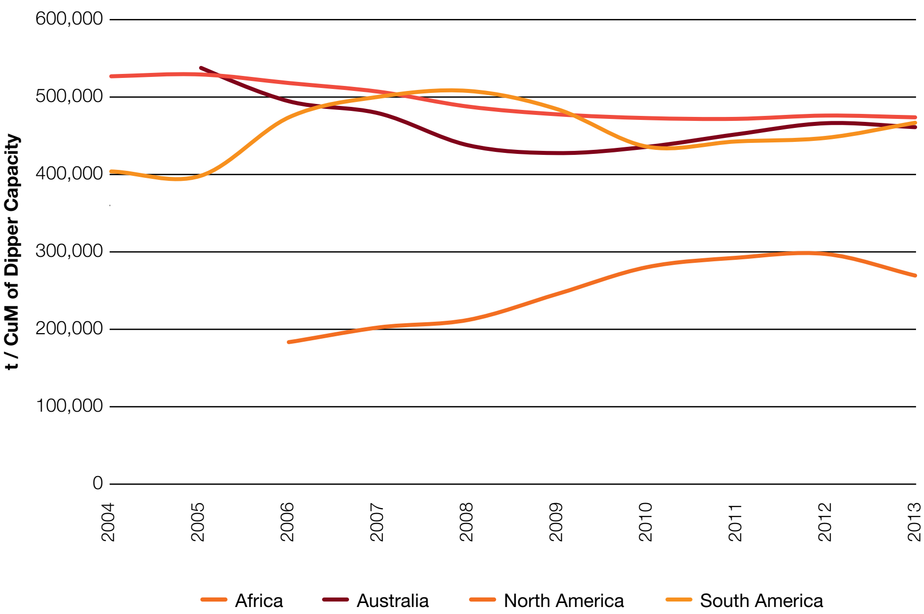


Figure 12: Rope Shovel Median Annual Unit Production (t/CuM of dipper capacity) 2004-2013 by Location



There is a range of performance trends visible between different locations. There is however, one interesting point. The performance (apart from Africa) does appear to be moving towards very similar median performance regardless of the location. North America generally achieved the highest annual output with Africa the lowest.

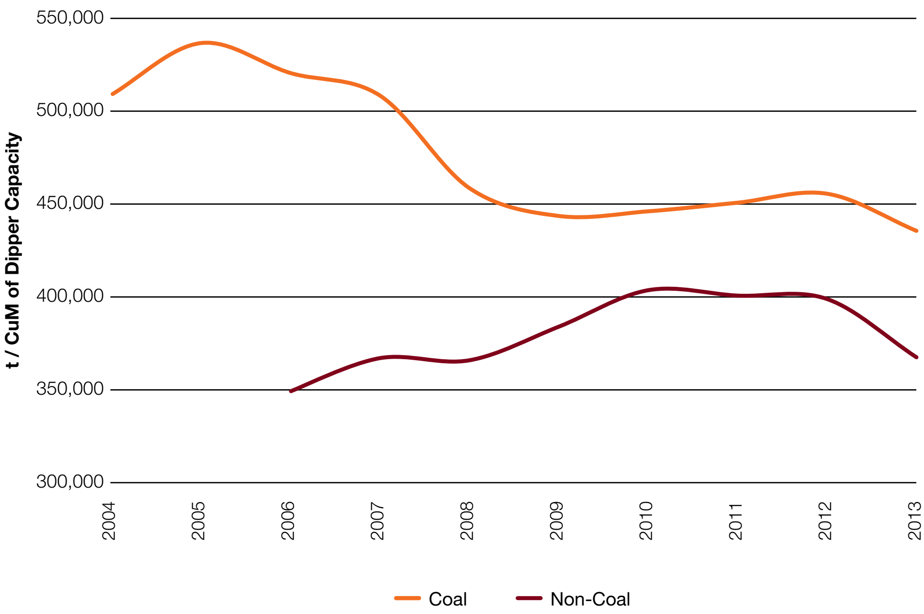
Figure 13 is a plot showing the differences between the performance of rope shovels used in coal mines and those in non-coal mines. Due to the quantity of data it is not possible to provide a valid breakdown by all commodities.

Different trends can again be seen in coal and non-coal, particularly prior to 2010. The performance of electric rope shovels in coal mines is higher than in non-coal mines. Coal mines achieved their peak in 2005 while the non-coal mines improved to 2012.

The final comparison is by make and model. Figure 14 shows the 2012 median performance for each make and model.

Most makes and models have again declined over time but the primary message in this plot is the significant differences amongst different makes and models. The differences are much larger than for draglines. The most productive make and model achieved 496,000 t / CuM of Dipper Capacity while the least productive achieved 149,000 t / CuM of Dipper Capacity. The lowest is 70% below the top (compared with 38% for draglines).

Figure 13: Rope Shovel Median Annual Unit Production (t/CuM of Dipper Capacity) 2004-2013 Coal and Non-Coal



As with draglines the unit output increases with increasing machine size. This is further demonstrated in the plot in Figure 15 which is Median Output versus Bucket Capacity. Bigger machines move more than smaller machines even after the results are modified to normalise differences in the capacity of the dipper. The increasing efficiency with capacity is more pronounced with rope shovels than with draglines. The line of best fit for loaders which load trucks is presented as a third order polynomial however, there are a number of different lines which could be fitted to this data. The reason for choosing the third order polynomial is that as newer larger equipment is introduced it is usual for performance of these models to be lower for some time. In the case of electric rope shovels the largest shovels, have been in the market for some time and performance is high so the levelling of this plot is not observed.

The correlation is reasonable. With an R2 of 0.76. The difference between machines of similar bucket capacity can be millions of tonnes per year. That material carries a significant value.

Figure 14: Rope Shovel Annual Unit Production (t / CuM of Dipper Capacity) 2012 by Make and Model

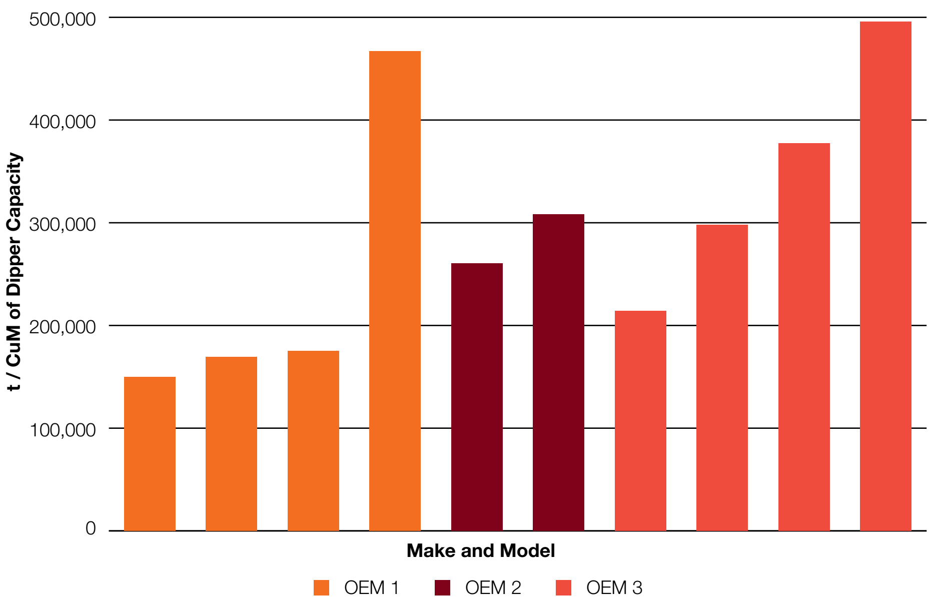
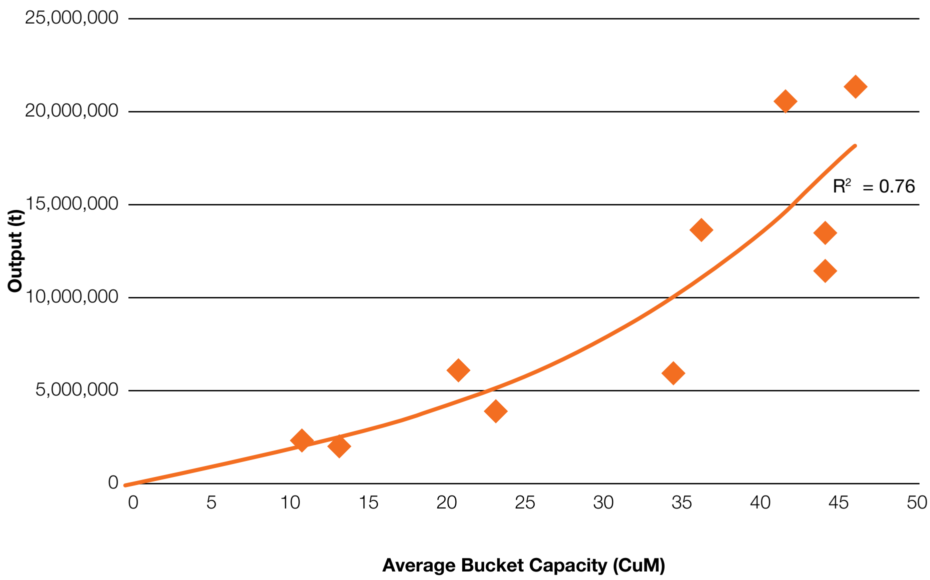


Figure 15: Rope Shovel 2012 Output Versus Bucket Capacity



Hydraulic Excavators (Face Shovel and Backhoe)

As of 30 September 2013, 4,239 hydraulic excavators were operating worldwide (Parker Bay Mining). In 2013 they will move around 35.3 Billion tonnes or 40% of total material movement.

Data pre-2002 is not of sufficient quantity and quality to provide a valid comparison. The 2002 - 2013 performance is shown in Figure 16 and demonstrates significant changes over this period.

The 2002 - 2013 trend for median excavator output rises to 2009 before falling significantly leading into 2013; 14% for median performance and 18% for best practice. The difference between median and best practice increased from 33% in 2002 to 96% in 2009 and has come back slightly to 85% in 2013.

Figure 16: Worldwide Hydraulic Excavator Annual Unit Production (t/CuM of Capacity) 2002-2013 by Performance

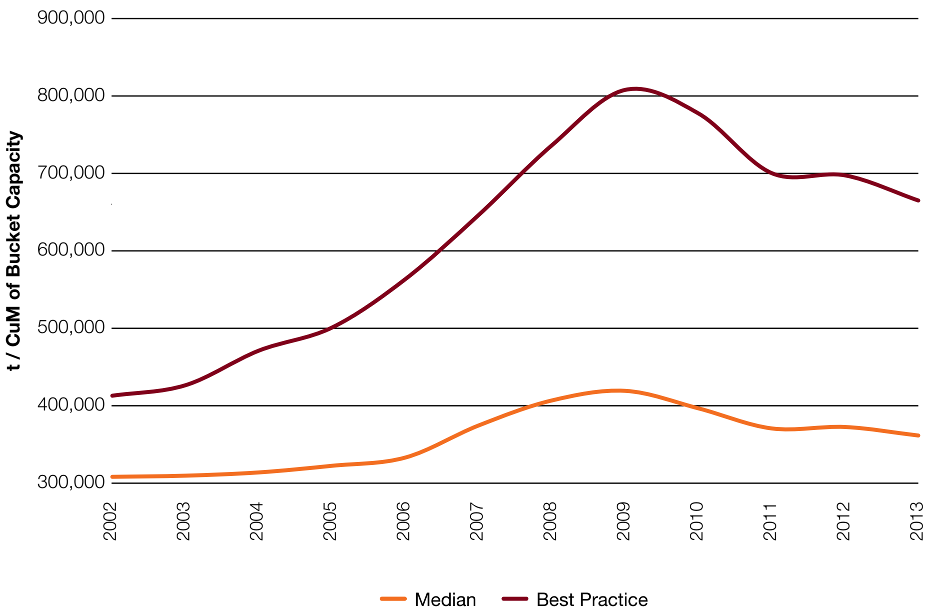


Figure 17 is a plot showing the differences amongst median hydraulic excavator performance in Australia, Africa, Asia, North America and South America.

There are two distinct trends observable. Firstly, Asia, Australia and Africa have been falling since 2007 / 2008. Secondly, North and South America rose strongly to 2010 / 2011 and have maintained the high levels up to 2013.

Figure 18 is a plot showing the differences between the performance of rope shovels used in coal mines and those in non-coal mines.

Figure 17: Hydraulic Excavator Median Annual Unit Production (t/CuM of Bucket Capacity) 2002-2013 by Location

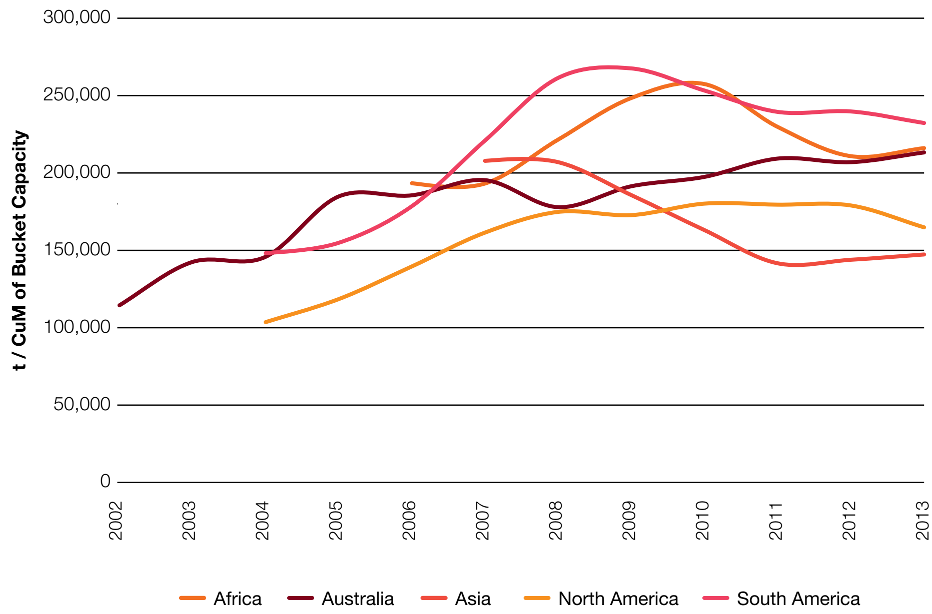


Figure 18: Hydraulic Excavator Median Annual Unit Production (t/CuM of Bucket Capacity) 2002-2013 Coal and Non-Coal

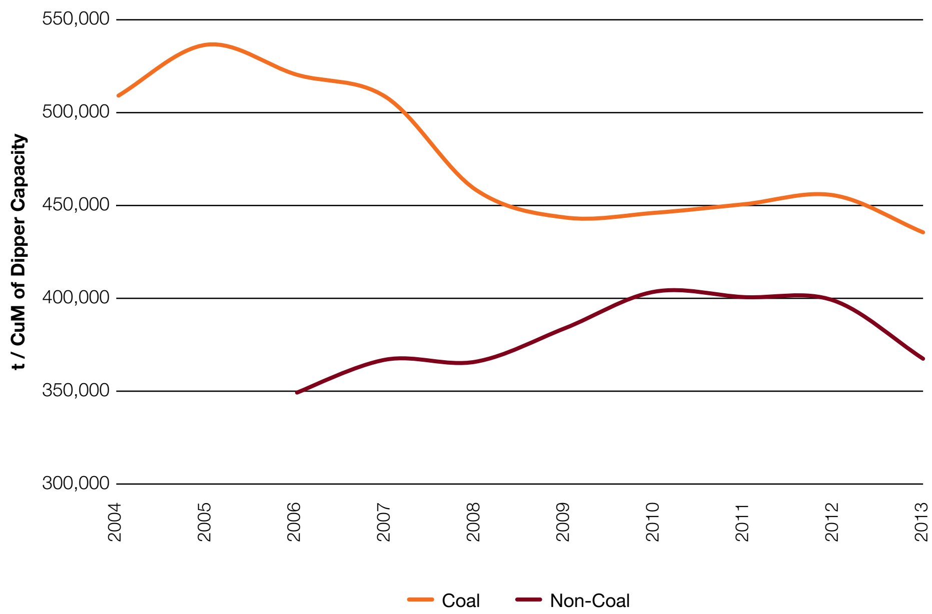


Figure 19: Hydraulic Excavator Annual Unit Production (t / CuM of Bucket Capacity) 2012 by Make and Model

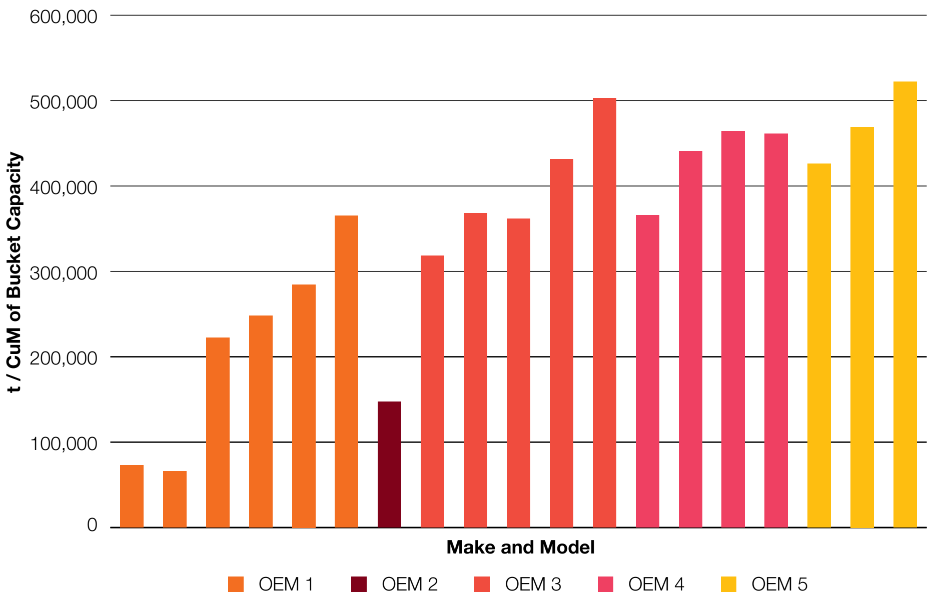
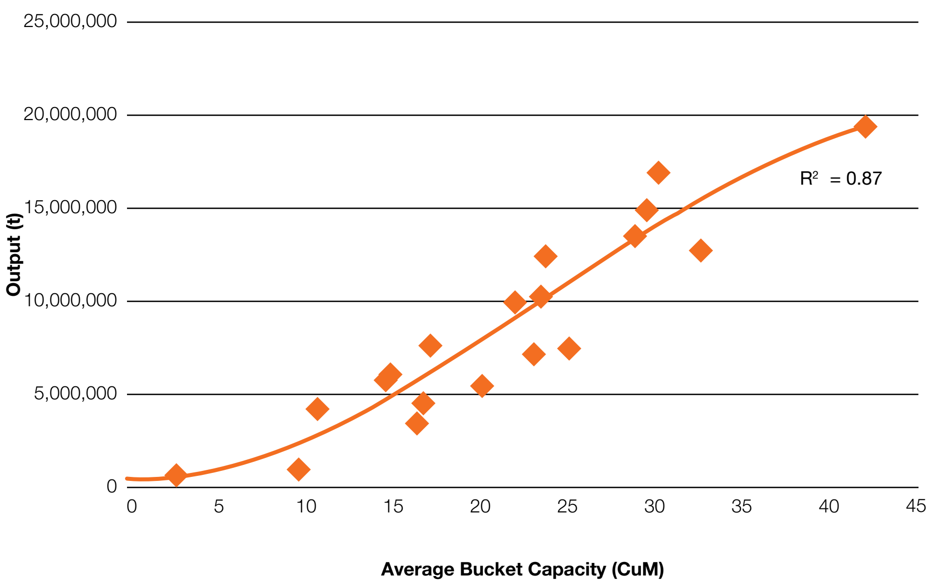


Figure 20: Hydraulic Excavator 2012 Output Versus Bucket Capacity



Different trends can again be seen in coal and non-coal, particularly prior to 2011. The performance of hydraulic excavators in coal mines is higher than in non-coal mines. Coal mines achieved their peak in 2008 while the non-coal mines improved to 2012.

The final comparison is by make and model. Figure 19 shows the 2012 median performance for each make and model.

The primary message in this plot is again the significant differences amongst different makes and models. The most productive make and model achieved 522,000 t / CuM of Bucket Capacity (two makes and models were higher than the highest electric rope shovel) while the least productive achieved 66,000 t / CuM of Bucket Capacity. The lowest is 87% below the top (compare with 38% for draglines and 70% for rope shovels).

A similar characteristic is seen with this data as with draglines and rope shovels. That is, the unit capacity increases with increasing machine size. This is demonstrated in the plot in Figure 20 which is Output versus Bucket Capacity. Up to around 35 CuM bucket capacity machines move more even after the results are modified to normalise differences in the capacity of the dipper. The ultra class excavators in 2012 were not as efficient which sees the plot start to level off.

The correlation is good although even with an R2 of 0.87 the difference between machines of similar bucket capacity can be millions of tonnes per year. That material carries a significant value.

Front End Loaders (Wheel Loaders)

As of 30 September 2013, 3,511 front end loaders were operating worldwide in the mining industry (Parker Bay Mining). In 2013 they will move around 10.2 Billion tonnes or 12% of total material movement.

Data pre-2002 is not of sufficient quantity and quality to provide a valid comparison. The 2002 - 2013 performance is shown in Figure 21 and demonstrates significant changes over this period.

The 2002 - 2013 trend for front end loaders is very similar to hydraulic excavators. The median output rose from 2002 to 2008 while best practice rose from 2002 to 2009. Both fell significantly into 2013; (23% for median performance and 19% for best practice). The difference between median and best practice increased from 25% in 2002 to 61% in 2013.

Figure 22 is a plot showing the differences amongst median front end loader performance in Australia, Africa, Asia, North America and South America.

There are again two distinct trends observable. Asia, South America and Africa have been falling for a number of years while North America and Australia have trended up for most of the time presented.

Figure 21: Worldwide Front End Loader Annual Unit Production (t/CuM of Capacity) 2002-2013 by Performance

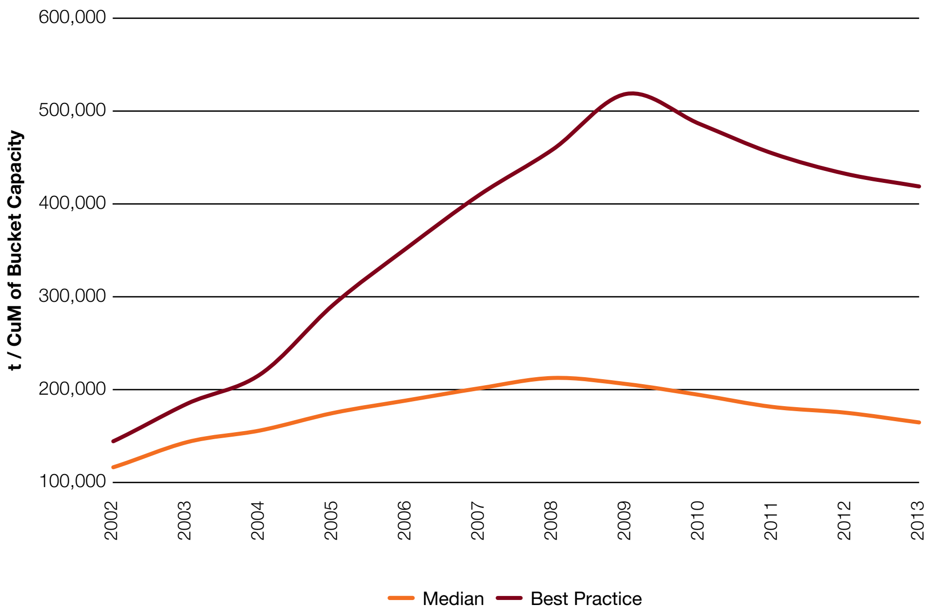


Figure 22: Front End Loader Median Annual Unit Production (t/CuM of Bucket Capacity) 2002-2013 by Location

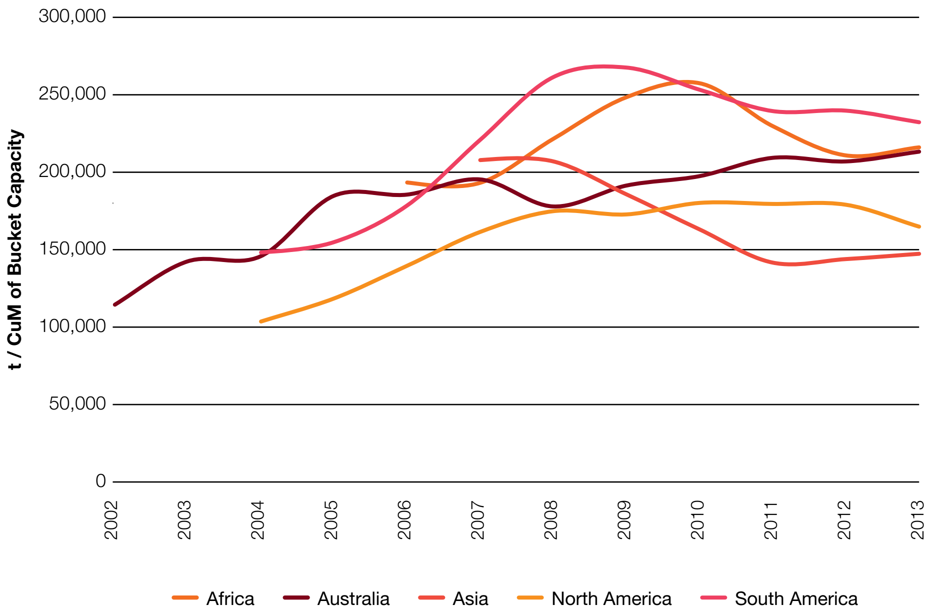


Figure 23: Front End Loader Median Annual Unit Production (t/CuM of Bucket Capacity) 2002-2013 Coal and Non-Coal

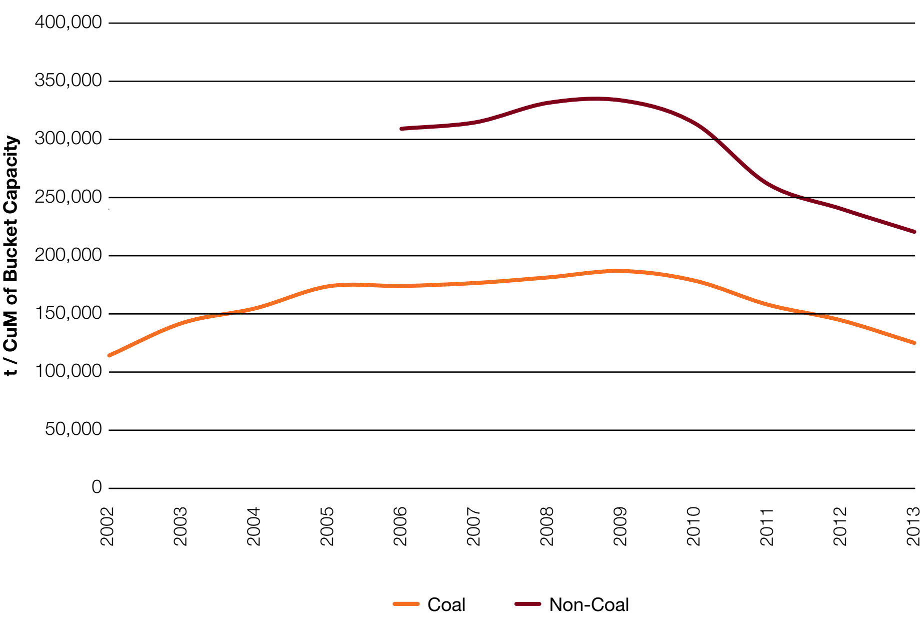


Figure 24: Front End Loader Annual Unit Production (t / CuM of Bucket Capacity) 2012 by Make and Model

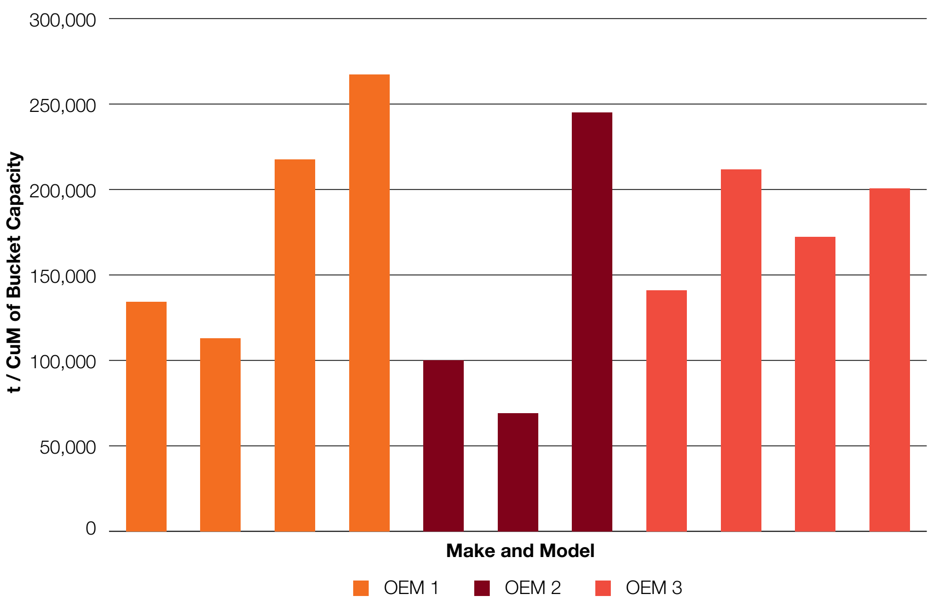


Figure 23 is a plot showing the differences between the performance of front end loaders used in coal mines and those in non-coal mines. Due to the quantity of data it is not possible to provide a valid breakdown by all commodities.

In the case of front end loaders, non-coal mines are more productive than coal mines. This is the opposite of rope shovels and hydraulic excavators. Both achieved their peak in 2009.

The final comparison is by make and model. Figure 24 shows the 2012 median performance for each make and model.

There is again a significant difference amongst different makes and models. The most productive make and model achieved 267,000 t / CuM of Bucket Capacity while the least productive achieved 69,000 t / CuM of Bucket Capacity. The lowest is 74% below the top (compared with 38% for draglines, 70% for rope shovels and 87% for hydraulic excavators).

A similar characteristic is seen with this data as with other loaders. That is, the unit capacity increases with increasing machine size up to a point and then levels off. This is seen in the plot in Figure 25 which is Output versus Bucket Capacity. Up to around 25 CuM bucket capacity machines move more even after the results are modified to normalise differences in the capacity of the bucket.

The correlation is good although with an R2 of 0.75 the variability being explained by bucket capacity is less than is the case for draglines, rope shovels and excavators. That is, the variability amongst makes and models is higher than other classes of equipment. By way of example, the makes and models with approximately 20 CuM bucket capacity can have between 3.3M tones moved per annum and 5.6 M tonnes per annum.

Mining (Haul) Trucks

As of 30 September 2013, ~38,500 mining trucks were operating worldwide (Parker Bay Mining). In 2013 they will carry around 73.9 Billion tonnes or 80% of total material movement in conjunction with loading tools.

The 2001 - 2013 performance normalised to six kilometre total equivalent horizontal haul distance is shown in Figure 26 and again demonstrates significant changes over this period.

The 2001 - 2013 trend for mining trucks is very similar to other loaders although the peak occurred earlier (except for rope shovels).

The median performance rises from 11,476 tonnes per tonne of nominal truck payload in 2002 to 13,963 tonnes per tonne of nominal truck payload in 2006; a rise of 22% in 4 years. Best practice performance rises more in absolute terms but not as much in percentage terms. Best practice rises from 15,722 tonnes per tonne of nominal truck payload in 2001 to 21,341 tonnes per tonne of nominal truck payload in 2006; a rise of 36% in 5 years. As has happened with loading units, performance has fallen over the last few years. Best practice and median truck performance have fallen 32% and 18% respectively from the peak over the last six years. The difference between median and best practice increased from 33% in 2001 to 82% in 2013.

Figure 25: Front End Loader 2012 Output Versus Bucket Capacity

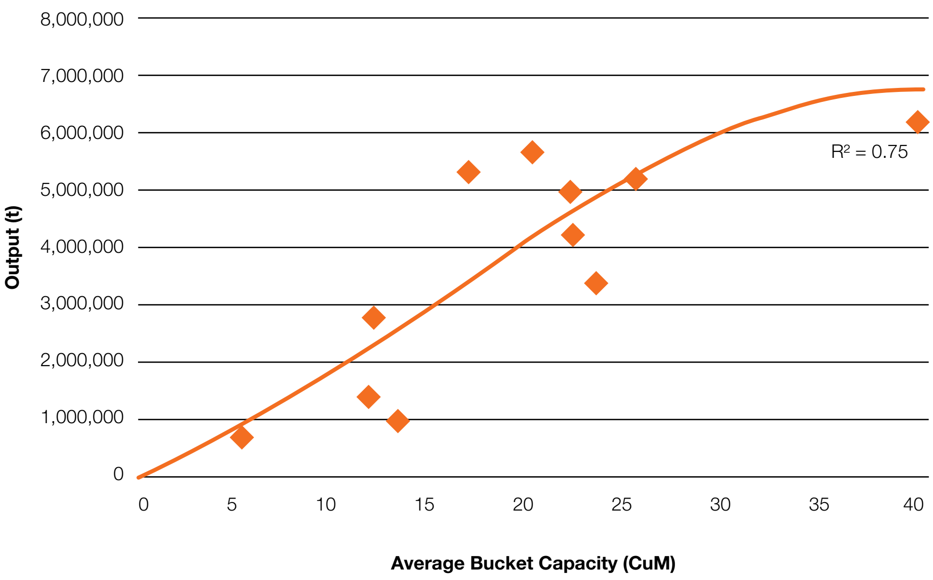


Figure 26: Mining Truck Annual Unit Production (t/tonne of Nominal Payload) 2001-2013 by Performance

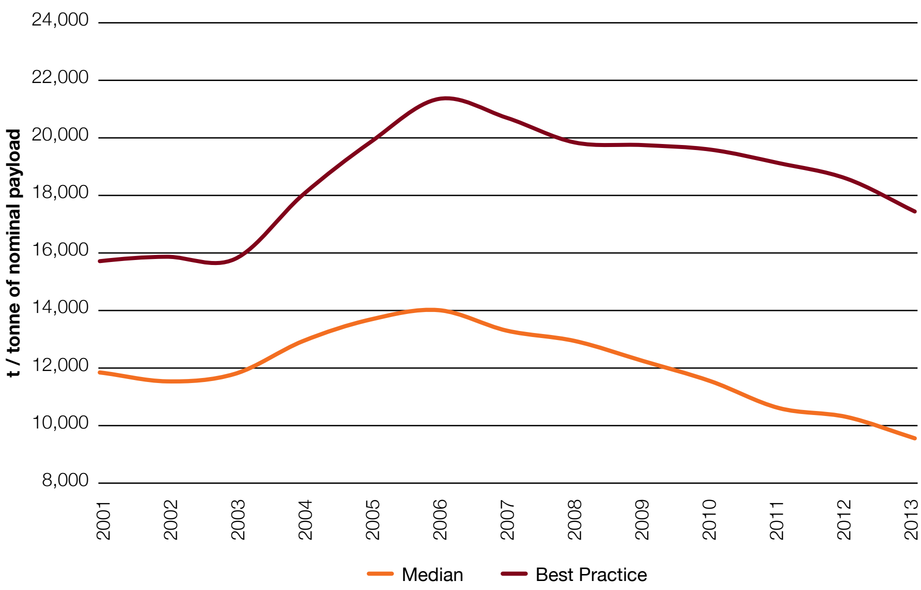


Figure 27: Mining Truck Annual Unit Production (t/tonne of Nominal Payload) 2001-2013 by Location

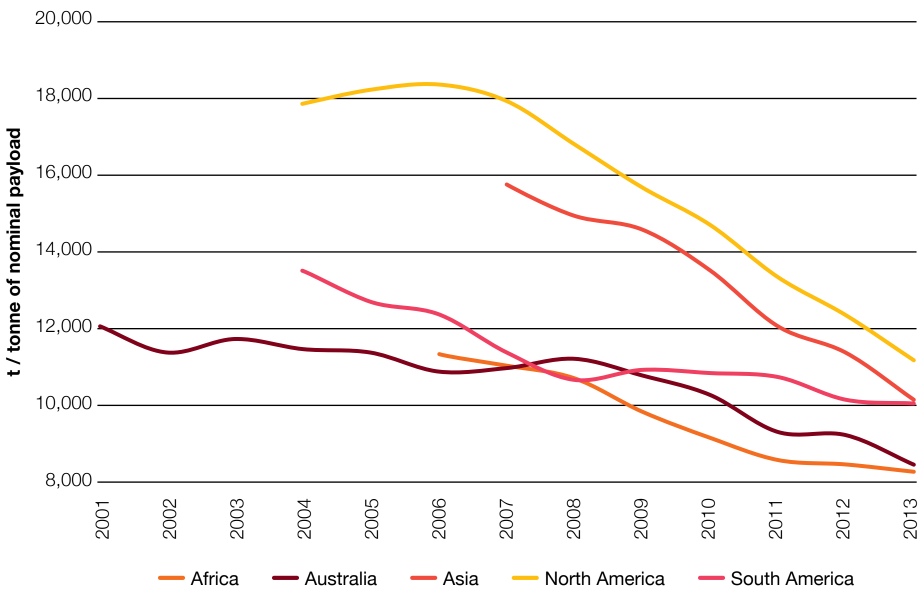


Figure 28: Mining Truck Annual Unit Production (t/tonne of Nominal Payload) 2001-2013 Coal and Non-Coal

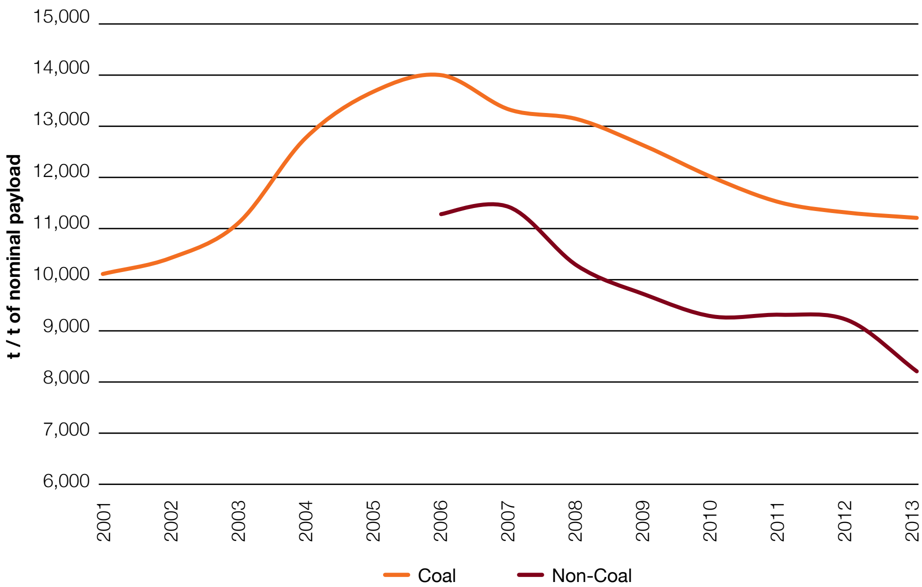


Figure 27 is a plot showing the differences amongst median truck performance in Australia, Africa, Asia, North America and South America. The results are again normalised to a six kilometre total equivalent horizontal haul distance.

Most mining jurisdictions have seen a decline in truck performance during the last 6-8 years. The declines in North America and Asia, where performance was much higher, have been more pronounced and have brought performance to a point where the differences between locations is much less.

Figure 28 is a plot showing the differences between the performance of mining trucks used in coal mines and those in non-coal mines. Due to the quantity of data it is not possible to provide a valid breakdown by all commodities.

In the case of mining trucks, coal mines are more productive than non-coal mines.

Figure 29: Mining Truck Annual Unit Production (t / tonne of nominal payload) 2012 by Make and Model

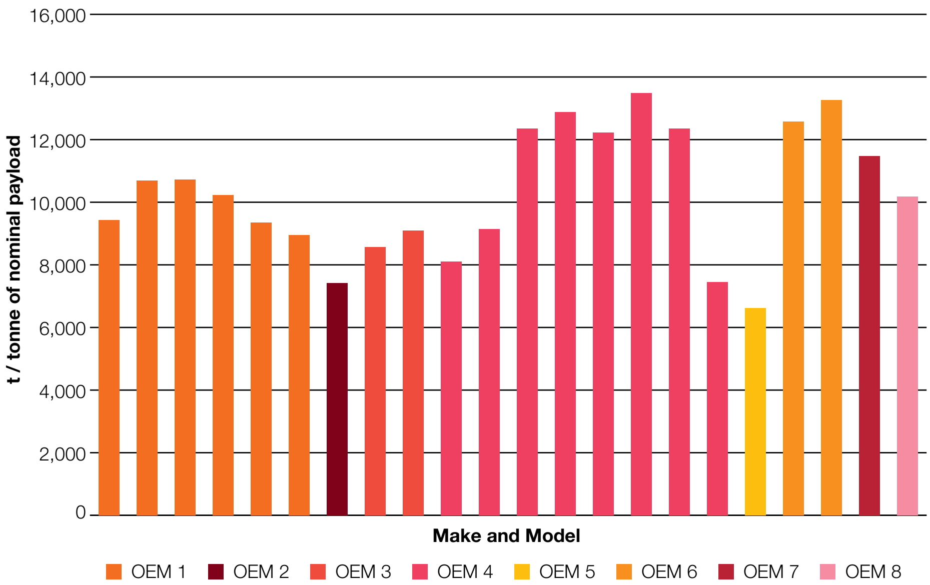
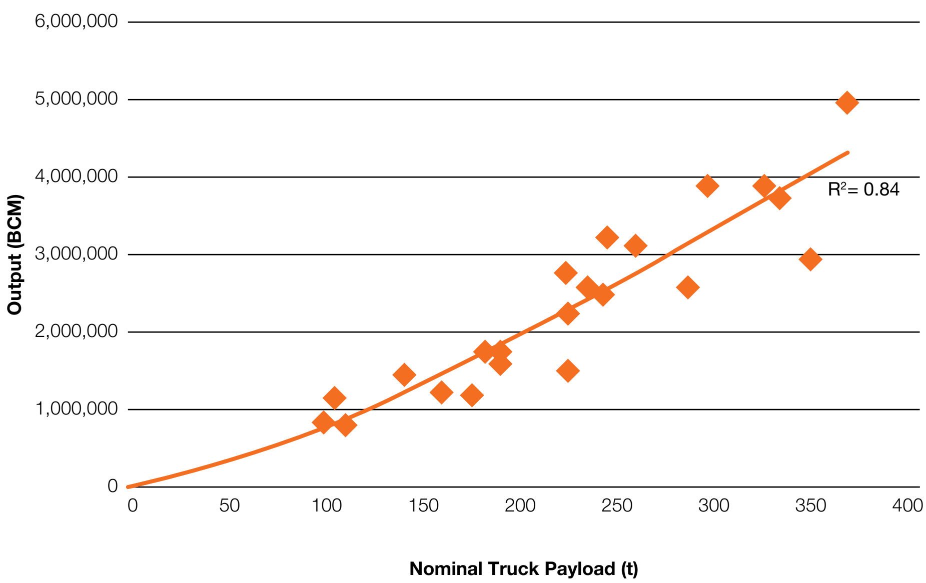


Figure 30: Mining Truck 2012 Output Versus Nominal Payload



The final comparison is by make and model. Figure 29 shows the 2012 median performance for each make and model.

There are again significant differences between different makes and models. The most productive make and model achieved 13,485 t / tonne of nominal payload while the least productive achieved 6,617 t / tonne of nominal capacity. The lowest is 51% below the top.

The characteristic of unit capacity generally increasing with increasing machine size is not consistent in this plot although when the makes and models are plotted together (Figure 30) up to around 200 tonnes nominal payload trucks move more even after the results are modified to normalise differences in the capacity of the bucket.

The correlation is good with an R2 of 0.84 . However, again by way of example, the ultra-class makes and models (nominal payload >300 tonnes) move between 2.9 M tonnes per annum and 4.9 M tonnes per annum.

Mining excellence at PwC

Delivering local solutions to global challenges

The mining sector is facing a range of competing trends and a rapidly changing global business environment. Against the backdrop of commodity price fluctuations, miners need to balance shareholder dividend expectations whilst maintaining an investment pipeline in the midst of increasing operating costs. Safety, environmental and community principles also continue to shape the industry as miners look to achieve their licence to operate and deliver on corporate responsibilities.

Mining Excellence at PwC has been designed to mobilise and leverage PwC's collective global knowledge and connections to deliver an exceptional and tailored client experience, helping our clients navigate the complex industry landscape and meet their growth aspirations. Our team of specialists is exclusively focused on the sector and brings an industry-based approach to deliver value for you and your organisation.

"The positive story for miners is that the long-term growth fundamentals remain intact. But, mining companies are facing significant downward pressure. As an industry, we need to fully address the confidence crisis, before we are able to move on the next phase of the cycle."
John Gravelle, PwC Global Mining Leader

Mining Excellence at PwC provides our clients:

leading edge ***knowledge*** *and insight*

With significant investment in the research behind our mining publications and a comprehensive industry learning and development program, our professionals can share both industry and technical insight with our clients, such as:

- A library of industry publications designed to help challenge "conventional" thinking and delve into topical industry issues. This includes:
  - flagship publications including *Mine* and *Mining Deals*
  - The *Insight Series* focuses on specific issues most important to miners

- An extensive industry development program for our people and clients. This features our annual university-style courses:
  - *Hard Hat: The Mining Experience* (Australia)
  - *Americas School of Mines* (North America)
  - *London School of Mines* (United Kingdom)
  - *Asia School of Mines*

connections *to our vast network of mining experts and global client portfolio*

We have the widest network of industry experts who work out of strategic mining hubs across the globe to help better connect you to vital mining markets.

Our connections provide:

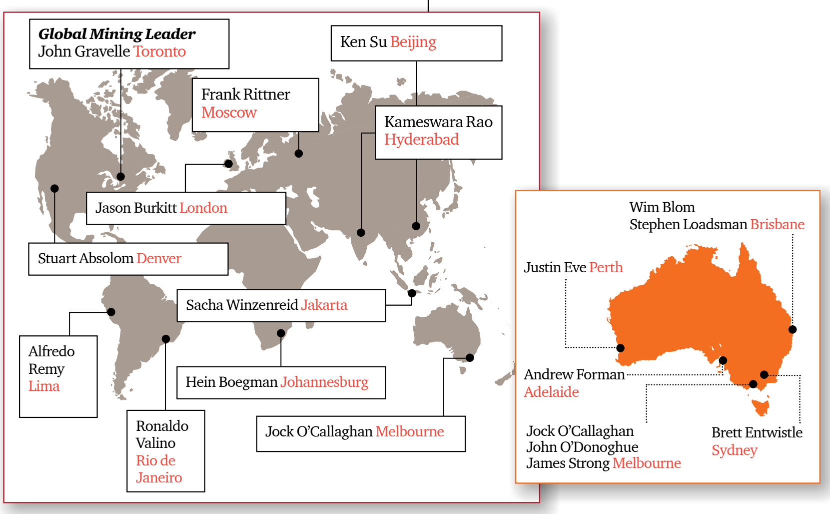
- seamless client service delivered with collaborative cross-border account management
- maximised deal potential through a well-connected global community of mining leaders
- a well-connected and mobile workforce to ensure effective service delivery in even the most remote mining locations.

the ***delivery*** *of an experience that meets our clients' definition of 'value'*

With mining experts working around Australia our award winning teams are helping clients deliver on specific projects and organisational productivity and growth aspirations. We offer operational consulting, deals, tax and audit services to global corporations and locally listed companies.

Mining Excellence at PwC complements this with:

- a suite of niche mining consulting capabilities focused on optimising value across mining operations and effectively managing risk to help our clients grow their business and deliver shareholder value
- a comprehensive client feedback program to ensure we are always improving and delivering on individual client needs.



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In 1999 Graham started GBI Mining and commenced building the GBI open cut mining equipment performance database. In September 2013 PwC completed the acquisition of the database and associated IP from GBI. Graham is now PwC's Director – Mining Intelligence and Benchmarking.

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