TRENDS IN PERFORMANCE OF OPEN CUT MINING EQUIPMENT

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INTRODUCTION

The objective of this paper is to provide information on trends in productivity of open cut mining equipment since 1994. Data has been collected from dragline monitor databases since 1994 and other equipment databases since 2002. This database constitutes the only significant collection of performance data relating to open cut mining equipment productivity and reliability in the world. This data covers the makes and models of equipment shown in Table 1. A number of these models are no longer manufactured or have been replaced post-company takeovers. A number of other makes and models are in the database but in insufficient numbers to make a statistically valid assessment.

As at December 2011, the database contained;

- 1 012 years (270M+ cycles) of dragline data;
- 346 years (90M+ cycles) of electric rope shovel data;
- 453 years (130M+ cycles) of hydraulic excavator data;
- 429 years (110M+ cycles) of front end loader data and
- >6 000 years (100M+ cycles) of mining truck data.

The exact number of truck years is almost impossible to calculate. There are 3,505 individual yearly summary entries however a number of the entries are for multiple truck numbers, ie. the entry is for a fleet rather than a single truck. This is because some mines only report trucks as a fleet rather than individually.

Draglines	Excavators	Front End Loaders	Electric Rope Shovels	Trucks	Drills	Dozers
BE1260W	Caterpillar 325 DL	Caterpillar 988	Marion 301 M	Caterpillar 777	BE 39R	D10N / R
BE1300W	Caterpillar 375	Caterpillar 992 D/G	Marion 351 M	Caterpillar 785B	BE 49R	D11N / R
BE1350W	Caterpillar 385 BL	Caterpillar 994 D/F	BE 295 B	Caterpillar 785C	BE 59R	Komatsu 375
BE1370W	Caterpillar 5130 / B	Komatsu WA800	BE 495 B/BI/BII	Caterpillar 789B	BE 61R	Komatsu 475
BE1570W	Caterpillar 5230	Komatsu WA900	BE 495 HR	Caterpillar 789C	DT D25	
BE2570W	Demag H285	Komatsu WA1200	P&H 2100 / BL	Caterpillar 793	DT D40	
BE2570WS	Demag H385	LeTorneau LT1100	P&H 2300 XP/LR	Caterpillar 797	DT D400	
Marion M7700	Demag H485	LeTorneau LT1350	P&H 2800XP/A/B	Euclid EH3000	DT D45	
Marion M7900	Hitachi EX 200	LeTorneau LT1400	P&H 4100 A	Euclid EH5000	DT D55	
Marion M8050	Fiat-Hitachi 285S	LeTorneau LT1800	P&H 4100XPB	Euclid R170	DT D75	
Marion M8200	Hitachi EX 1200	LeTorneau LT1850	P&H 4100 XPC	Komatsu 630EH	DT D90	
Marion M8200S	Hitachi EX 1800		P&H 5700	Komatsu 730E	GD 70	
Marion M8750	Hitachi EX 2500			Komatsu 830E	GD 120	
Page 740	Hitachi EX 3500			Komatsu 930E	IR DML35	
Page752	Hitachi EX 3600B/E/R			Liebherr T262	IR DMLSP	
Page 757	Hitachi ZX470LCH			Liebherr T282	IR DMLM 2	
P&H 9020	Hitachi EX 5500			Terex MT3600	IR DMLM 3	
	Komatsu H 655			Terex MT3700	IR DMLM Pit Viper	
	Komatsu PC 210LC			Terex MT4400	P&H 120	
	Komatsu PC 1250			Wabco 170E170E	P&H XP 250	
	Komatsu PC 1600				SVE SK 50	
	Komatsu PC 3000					
	Komatsu PC 4000					
	Komatsu PC 5500					
	Komatsu PC 8000					
	Terex O&K RH 120					
	Terex O&K RH 170					
	Terex O&K RH 200					
	Terex O&K RH 340					
	Liebherr R994					
	Liebherr R996					

Table 1. Makes and Models of Mining Equipment in GBI Database

This paper will not include drills or bulldozers. This is partly due to the quality of data from these pieces of equipment being doubtful. There is also significant analytic work being done on drills and bulldozers to increase understanding of how the data relates to what is actually happening on the mines. At this stage the author is not prepared to present this data

This data provides a valuable insight into performance and trends for the major types of equipment, ie. draglines, electric rope shovels, hydraulic excavators (backhoe and face shovel), front end loaders and mining trucks.

This paper presents the data in a range of forms which help the reader understand and interpret the data and the trends better. Performance is defined as either median, (middle), and best practice (average of the top decile which approximates the 95th percentile). Best practice is theoretically what the class of equipment is demonstrably capable of and median represents collectively what the industry is actually doing with the class or model of equipment. The data is analysed and presented as it is. The analysis has not sought to paint any particular picture nor has it biased the actual data in any way. While making comment on the trends, this paper has not sought to interpret the factors which have led to the trends. It is expected that others may be able to prepare discourses on the reasons for the trends and ways of learning from the information contained herein. The challenge is what to do about trends in efficiency both as an industry; as individual mines; and as individual people working in the mines.

A RECENT HISTORY OF PRODUCTIVITY IN AUSTRALIAN MINES

Lumley (2009) outlined a brief history of Australian mine productivity. Many people believe that 21st century open cut mining in Australia, or when being done by Australian companies, is a mature and efficient exercise. It might be mature but it is certainly nowhere near as efficient as it could be. This is despite significant improvements achieved over the last 20 years which have come about through the reduction of restrictive work practices and structural change in the industry. Shareholders have been told that Australian open cuts are now among the most efficient in the world. But the bottom line is the average mine or contractor is not doing the right thing by their shareholders and utilising the very expensive equipment at anything approaching best practice productivity.

While being of vital importance to the Australian economy, the mining industry from the early 1980’s to the 1990’s provided little in the way of profitability to the owners. During the 1960’s and

1970’s, an industry-wide culture of industrial deadlock and regulatory institutions that quarantined Australian operations from global competitive pressures, made workplace reform very difficult (Goldberg 2003). The wealth generated from mining operations provided relatively little for the shareholders. Australia went through a period of ‘profitless prosperity’ (Clifford 2002, p. 3). By the mid-1980’s, parts of the Australian mining industry started to respond to the opportunities and threats of globalisation. For example, the experience at Robe River in Western Australia where Peko Wallsend terminated the workforce in 1986 due to restrictive work practices (Copeman 1990), was more than ten years prior to Rio Tinto taking on similar restrictive work practices in their coal mines. In terms of safety, productivity and profitability, by the 1990’s coal operations were increasingly out of step (Goldberg 2003). During a six-week strike at one Rio Tinto coal mine the non-union employees (management, technical and administrative) ran the entire operation including operating the large mining equipment. The performance, under abnormal circumstances, was not high, but this exercise indicated the efficiencies that a more flexible operation could achieve (Davies 2001).

The changes that took place in the mining workplace from the mid-1980’s to the late 1990s provided a significant improvement in employee productivity and an accompanying reduction in costs. Figure 1 shows the improvement in productivity at Robe River from 1973 to 1990. Figure 2 shows the improvement of New South Wales coal mines through the late 1990s. It is important to note however that each of these plots have demonstrated an improvement per employee. Consequently, the perception that the equipment is operating more efficiently or outputting more is wrong in many cases.

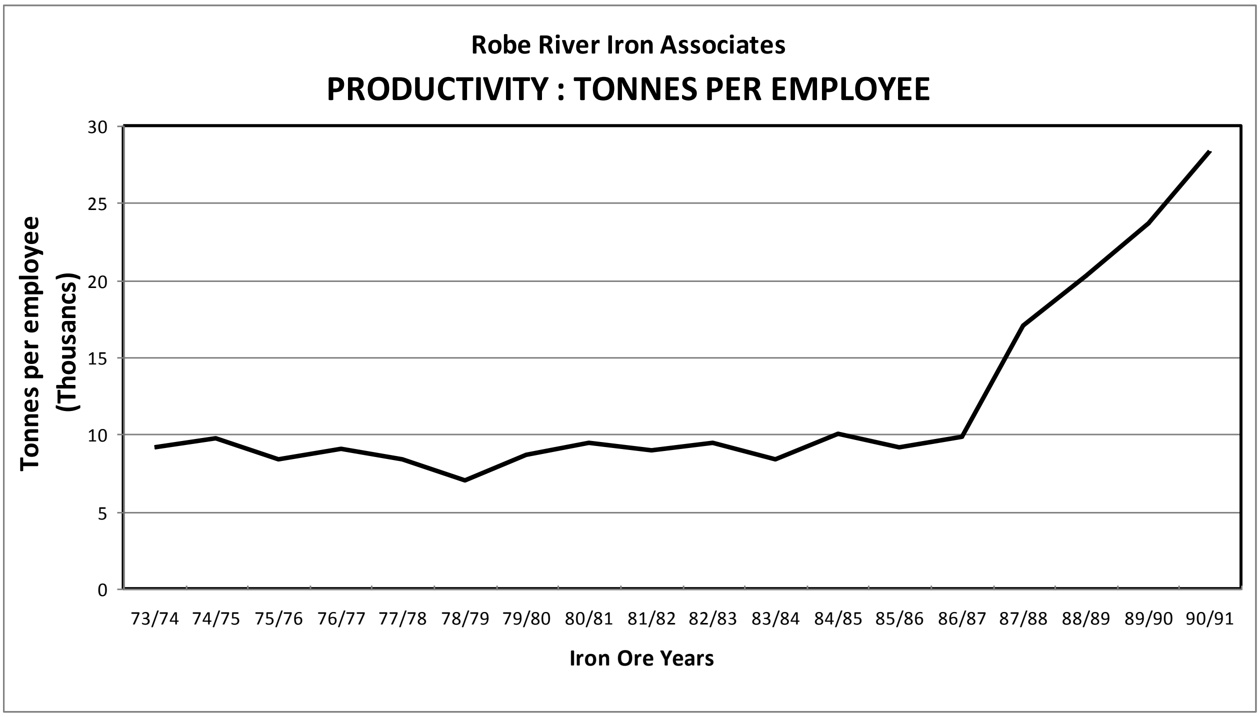

Figure 1- Productivity changes at Robe River (Copeman 1990)

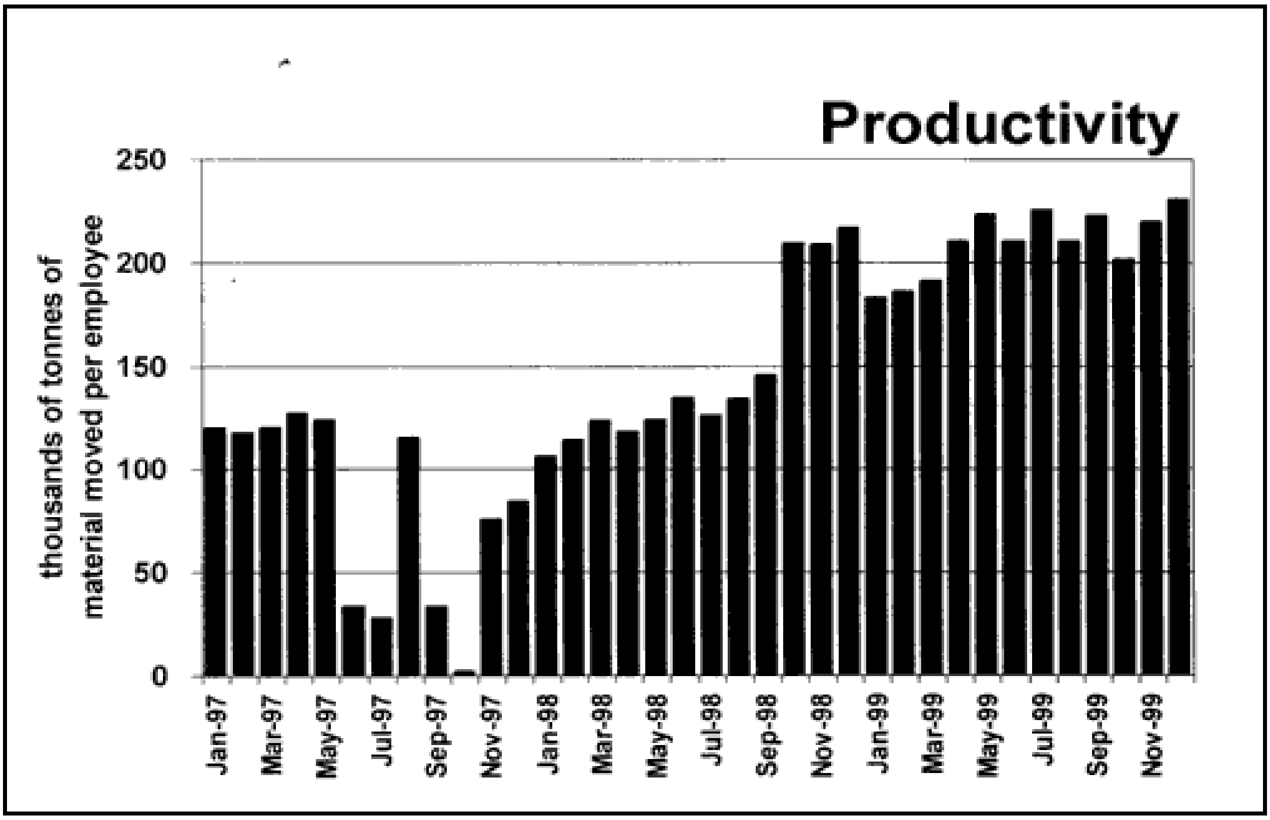

Figure 2- Productivity changes in NSW coal mines (Davies 2001, p3)

The Australian Bureau of Statistics publishes data for a range of industries allowing a measure of performance to be quantified (called Multifactor Productivity - MFP) and to allow performance between industries to be compared on a consistent basis. At the time of writing the last released data was for 2009/10. The plot of mining industry productivity and a basket of the 12 most significant industries to Australia's economy (including mining) is shown in Figure 3.

A number of significant insights can be gained from this graph;

1. There was a substantial rise in productivity in the mining sector from 1986-87 to 2000-01. The MFP rose from 92.6% to 146.0% of 1985-86 productivity (a rise of 58%) during this 14 year period.
2. There was a substantial decline in productivity in the mining sector from 2000-01 to 2009-10. In fact almost all the gains from 1986-87 were wiped out during this latter period leaving the industry performing at the same levels in 2009-10 as they were in 1986-87.
3. The performance of the 12 select industries shows a 20% gain over the same time frame

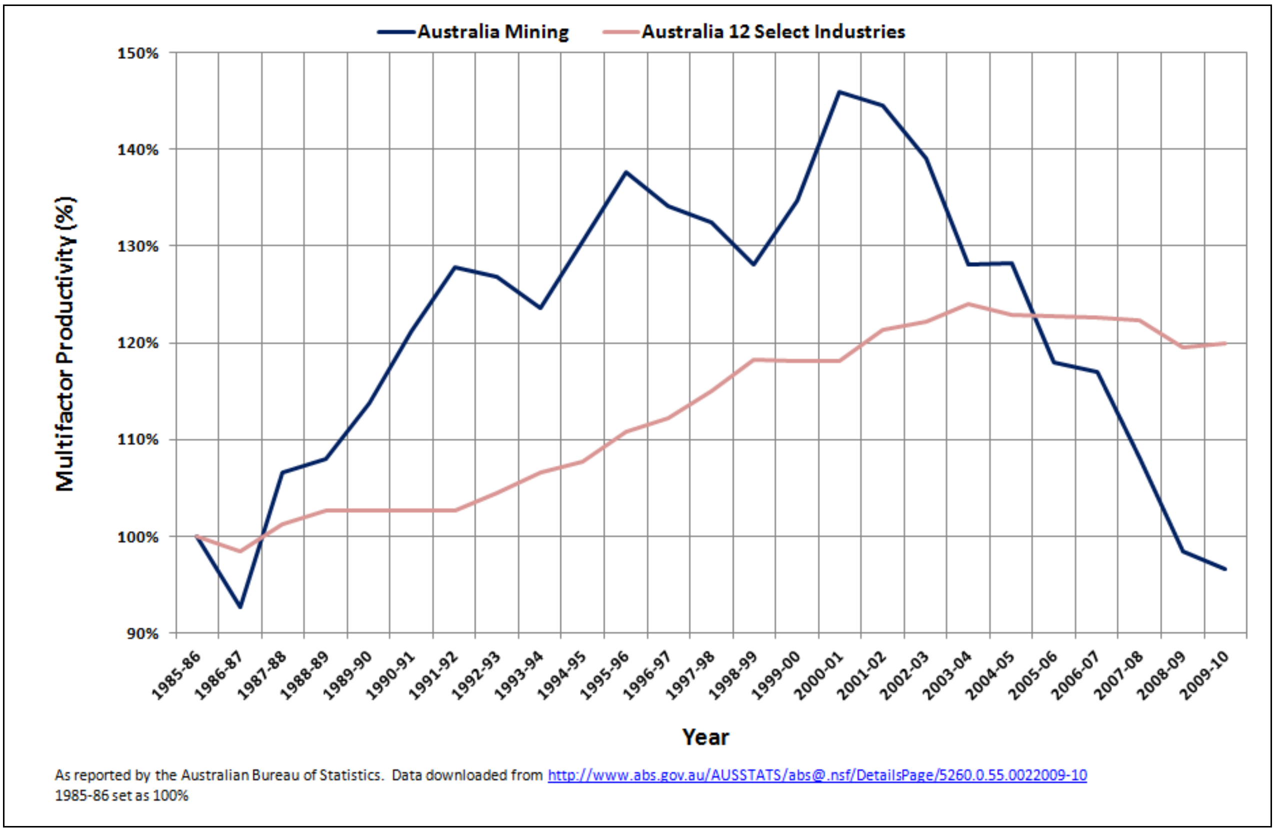

Figure 3. Multifactor Productivity 1985-86 to 2009-10

While mining industry revenue has grown rapidly over the decade, the volume of output has only grown at an annual average rate of 3 per cent, despite mining employment more than doubling and strong growth in capital stock. As a consequence, both labour productivity and MFP have fallen from 2001, when commodity prices started rising sharply (Figure 4).

OPEN CUT PERFORMANCE BY CLASS OF EQUIPMENT

Draglines

A dragline consists of a bucket which is suspended from a boom (a large truss-like structure) with wire ropes. The bucket is manoeuvred by means of a number of ropes and chains. The hoist rope, powered by large electric motors, supports the bucket and hoist rigging assembly from the boom. The dragrope is used to move the bucket and rigging horizontally. By moving the hoist and the dragropes the bucket is controlled through the action of a third rope – the dump rope, which is part of the rigging. This system of having a bucket unconstrained is unique in earthmoving equipment. A large dragline is shown in Figure 5.

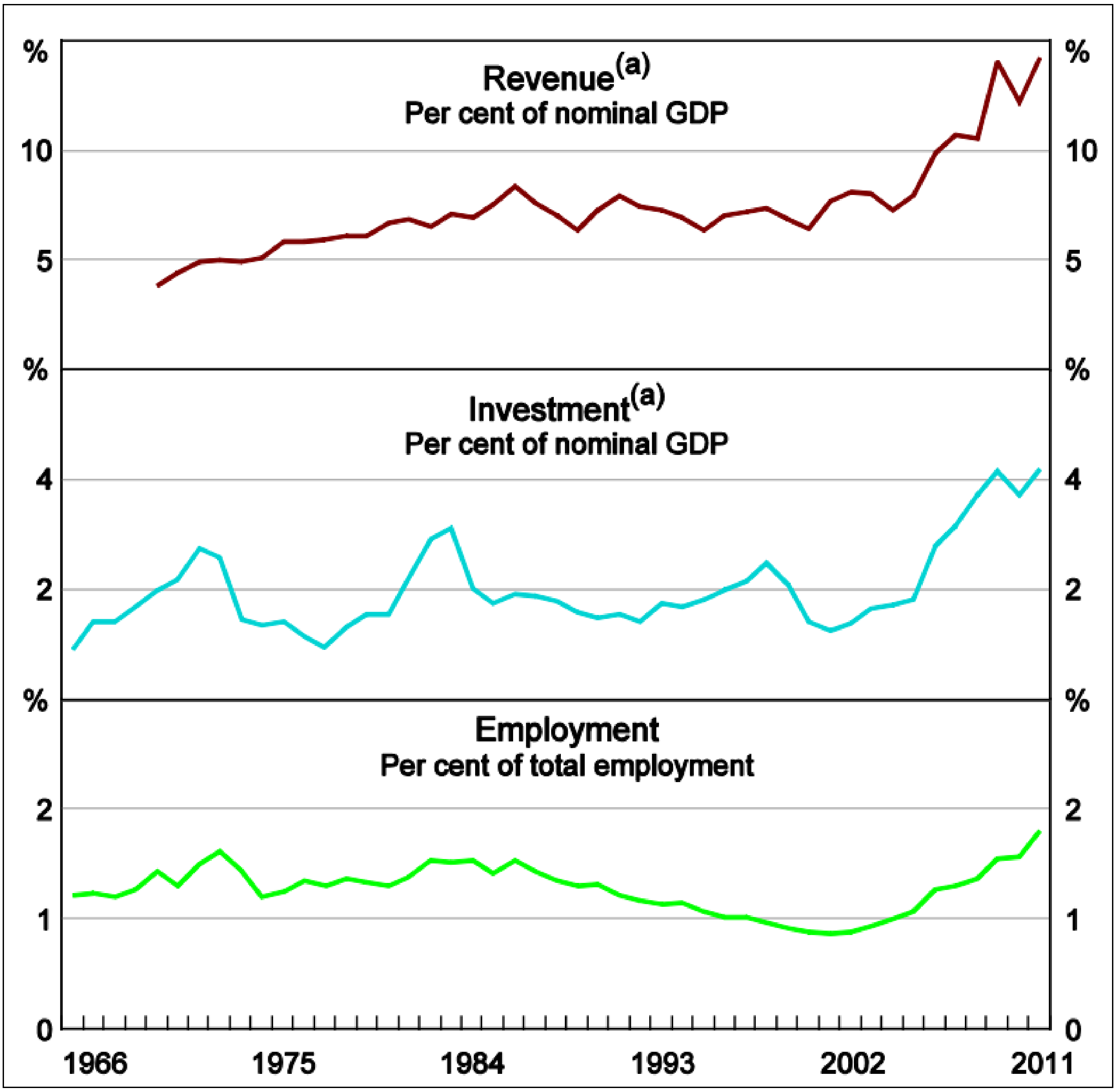

Figure 4.Mining Industry Statistics (reproduced from Connolly and Orsmond, 2011)

Figure 5. Large Walking Dragline

Draglines have been the primary stripping tool used on Australia's coal mines since the early 1970's. They are the most expensive tool to purchase and the cheapest to operate ($/BCM). A total of 70 large (20 m^3 – 120 m^3 bucket rated capacity) walking draglines are currently used in Australia. While continuing to be an integral part of many coal mines, their precedence and use (as a percentage of the total stripping capacity) has fallen over the last 10 years. A number of companies (but not all) are choosing the more flexible truck and loader systems to support expansions and new mine developments.

The performance of draglines is based on annual output in bank cubic metres (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. The RSL is a number which the manufacturer places on the machine as being a safe working load.

Figure 6 presents the trends in median and best practice annual output for worldwide draglines from 1994-2010.

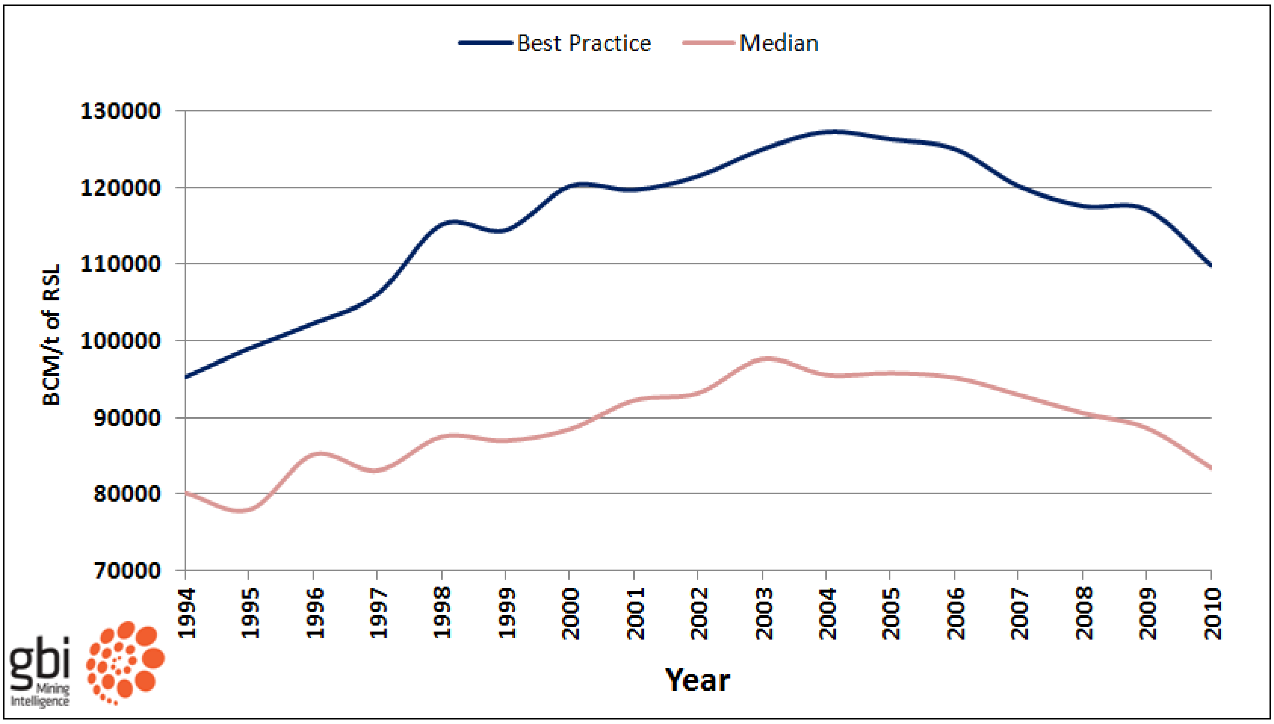

Figure 6. Worldwide Dragline Annual Unit Production (BCM/t of RSL) 1994-2010 by Performance

The same trends are seen for draglines as is seen for the MFP for all mining. The peak productivity for draglines occurred in 2003/2004 at around 127 000 BCM per tonne of RSL for best practice and 98 000 BCM/t for the median dragline. Both best practice and median performance has declined 15% since 2004 / 2003 respectively. The difference between median and best practice is reasonably consistent over the last 10 years, with best practice being between 28% and 32% higher than the median.

Figure 7 is a plot showing the differences between Australian dragline performance and those 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 and Europe but these have not been included due to lack of data and the generally smaller capacity in the case of Europe.

The same general trends can be seen in each country as is seen worldwide. There has been a peak between 2003 and 2006 with a subsequent decline. The decline is particularly evident in South Africa (-25%) and to a lesser extent in North America (-11%) and Australia (-9%).

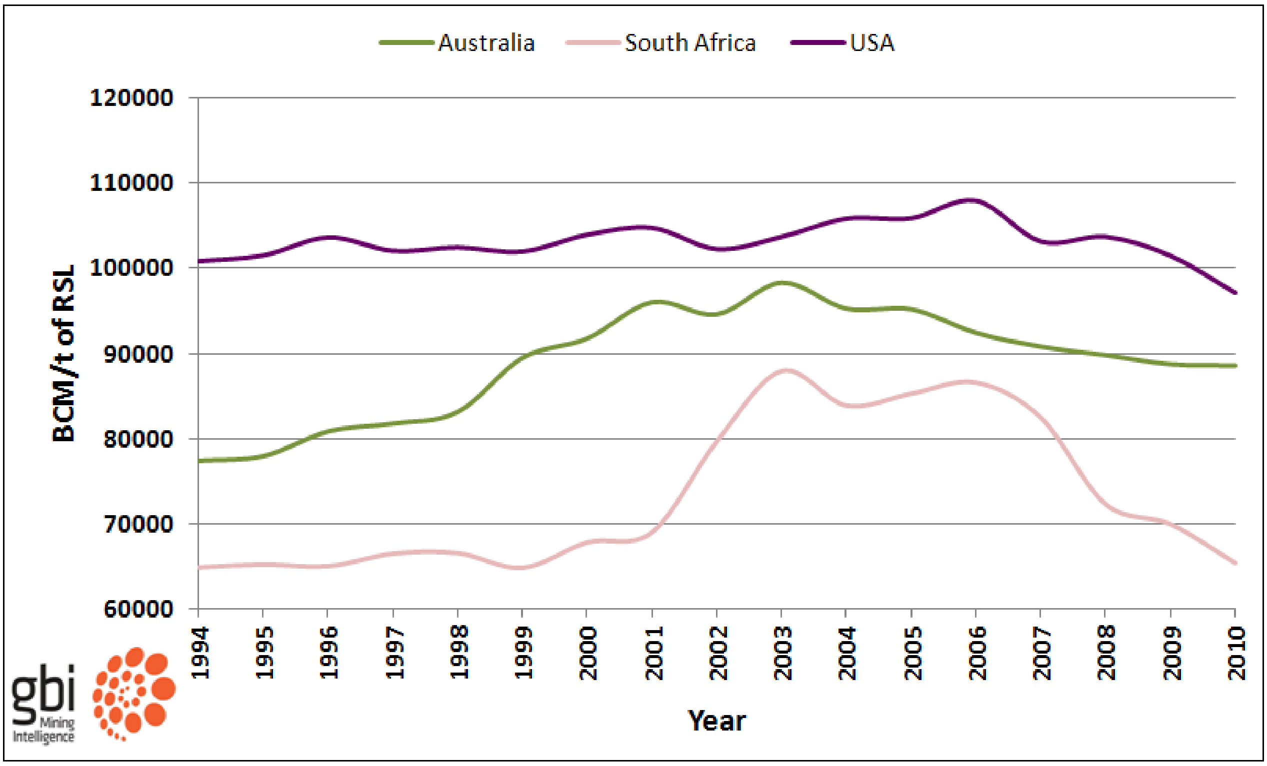

Figure 7. Worldwide Dragline Annual Unit Production (BCM/t of RSL) 1994-2010 by Performance

Figure 8 shows the median annual output of Australian draglines broken down between Queensland and New South Wales.

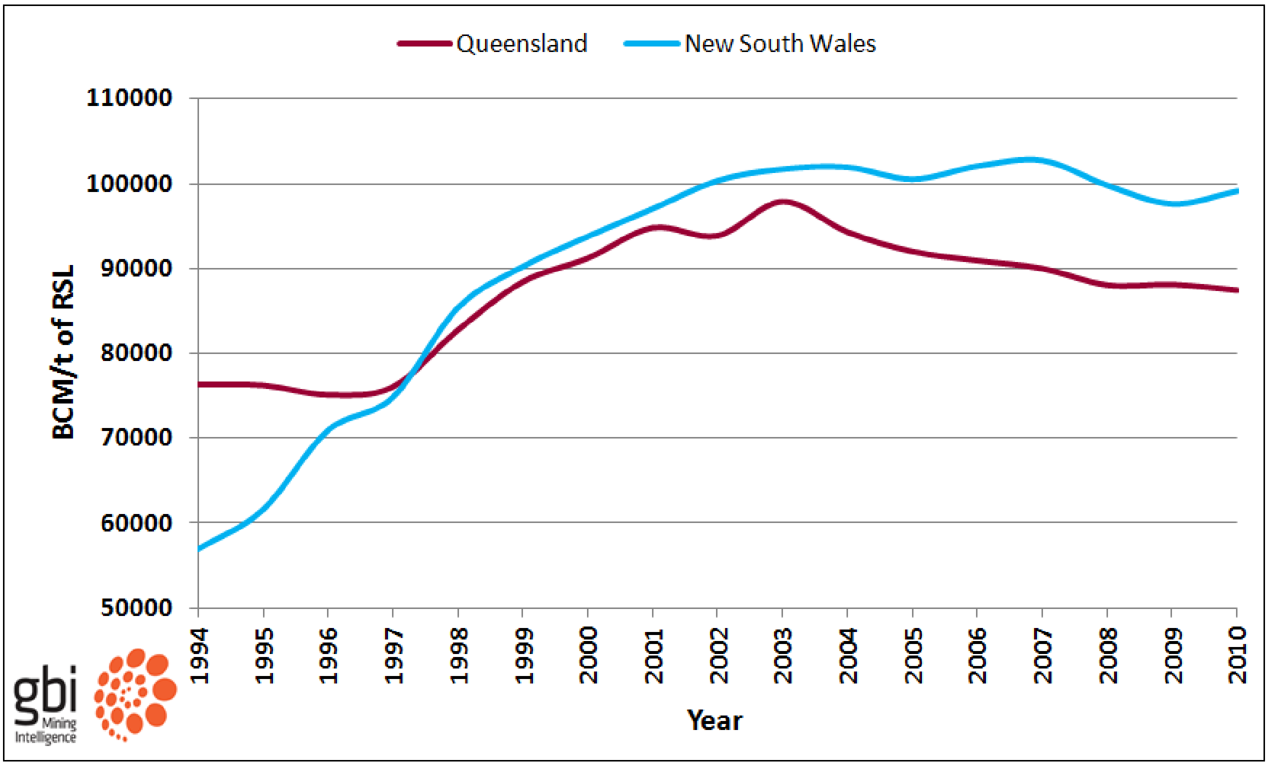

Figure 8. Australian Dragline Median Annual Unit Production (BCM/t of RSL) 1994-2010 by State

The early period between 1994 and 1997 saw median annual output of the NSW draglines underperform but improve rapidly and pass the Queensland median. The performance for both states improved over a number of years but post 2003 the Queensland draglines have declined (11%) and the NSW machines have maintained a higher level (decline has only been 5%).

The final comparison is by make and model. Figure 9 shows the 2010 median performance for each make and model.

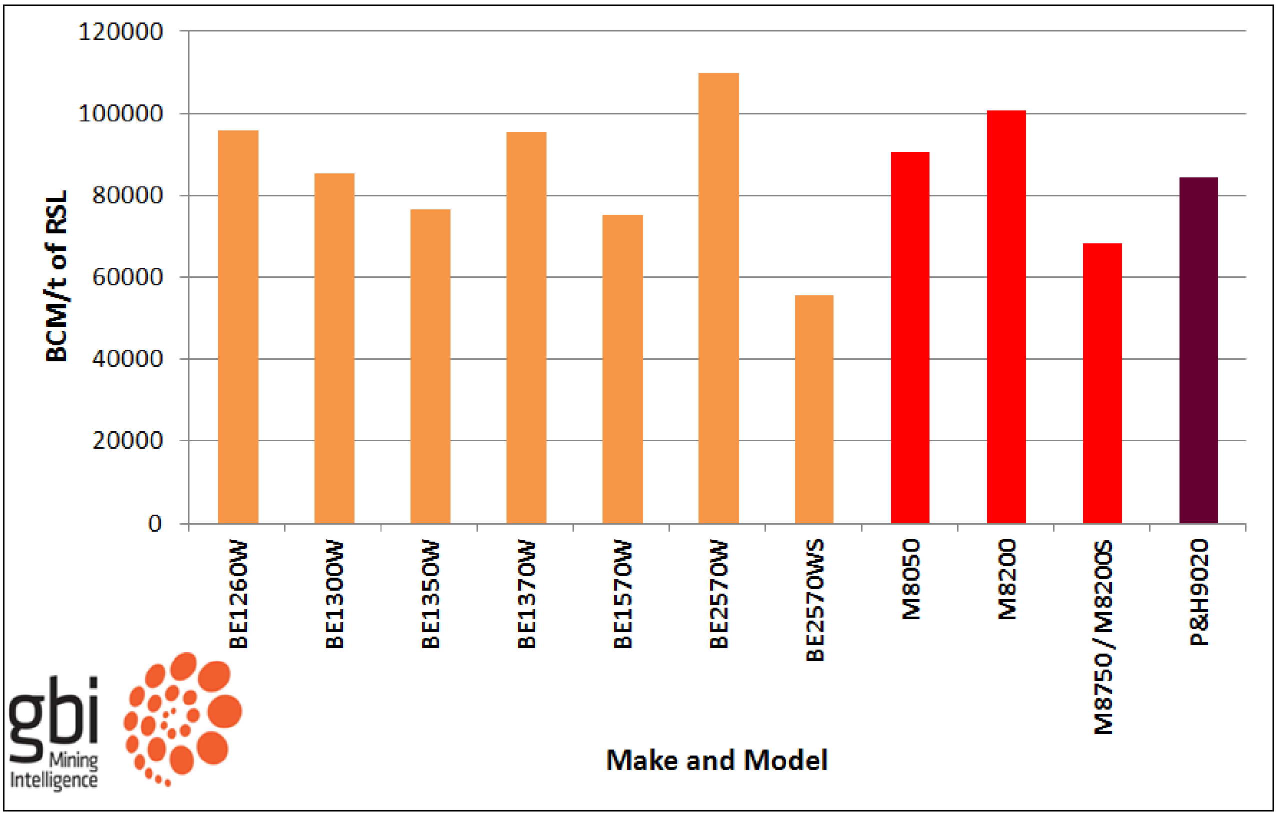

Figure 9. Dragline Annual Unit Production (BCM/t of RSL) 2010 by Make and Model

It is important to note that this plot does not attempt to say whether the make and model results actually reflect better draglines or the operating characteristics of the sites at which they are used. A number of the larger draglines are the lower performers. The M8750/M8200S (which have been combined as they are a very similar capacity) and BE2570WS are 38% and 49% below the BE2570W. The P&H9020 is 23% below the BE2570W.

Electric Rope Shovels

An electric rope shovel (also stripping shovel or front shovel or electric mining shovel) is a bucket-equipped machine used for digging and loading earth or fragmented rock and for mineral extraction. Shovels normally consist of a revolving deck with a power plant, driving and controlling mechanisms, usually a counterweight, and a front attachment, such as a boom which supports a handle / dipper arm with a bucket / dipper at the end. The machinery is mounted on a base platform with tracks. Rope shovels are used principally for excavation and removal of overburden in open-cut mining operations, though it may include loading of minerals, such as coal. Rope shovels exclusively load trucks for transporting material away from the loading area.

Electric Rope Shovels have gained significant usage on Australia's coal mines since the 1990's. They are not as widely used as draglines but are gaining increasing numbers. They are not predominant outside the coal mines but are used by a number of hardrock mines and contractors. Most rope shovels have 20 CuM+ dipper/bucket capacity. The latest large rope shovels have buckets >60CuM capacity with rated suspended loads up to 210 tonnes. They are not as efficient as a dragline in the percentage of material carried as a percentage of the material plus steel, however, they are more flexible than a dragline. They still suffer some inflexibility as most are electric and are not as flexible as a diesel loader. In bulk material movement large rope shovels can move material faster than the largest hydraulic excavators and front end loaders which have bucket capacities around 40CuM. Figure 10 shows a large electric rope shovel.

Figure 10. Electric Rope Shovel

The performance of rope shovels 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 report in bank cubic metres (tonnes/in-situ SG) while non-coal mines report in tonnes. In this paper performance has been presented in tonnes to allow consistency between electric rope shovels, hydraulic excavators and front end loaders (the primary classes of equipment loading 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 it is felt a more meaningful measure of a unit of input for a shovel is the bucket capacity. There is some inconsistency between how a rope shovel bucket capacity is defined and the way excavators and FEL's are defined, however this does not detract from the message contained in the trends.

Figure 11 presents the trends in median and best practice annual output for worldwide electric rope shovels from 2003-2010. Shovel data pre-2003 is not of sufficient quantity and/or quality to provide a valid demonstration of performance.

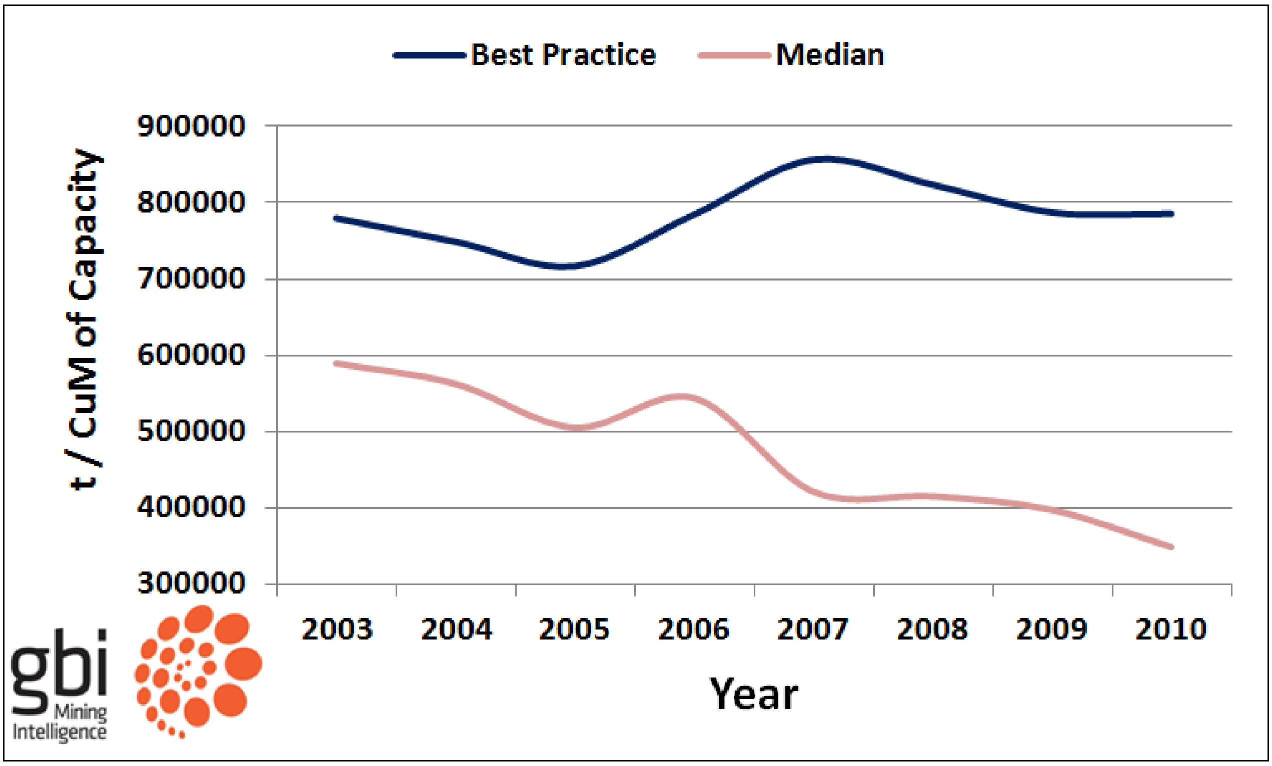

Figure 11. Worldwide Rope Shovel Annual Unit Production (t/CuM of Capacity) 2003-2010 by Performance

The 2003 - 2010 trend for median shovel output is down as it was for the MFP and draglines. The decline in median shovel output (41%) has been greater than for draglines with the median dropping from around 600 000 BCM per CuM of bucket capacity down to 350 000 BCM per CuM of bucket capacity. Best practice output peaked in 2007 at 856 000 tonnes per cubic metre of bucket capacity and subsequently declined 8% to 785 000 tonnes per cubic metre of bucket capacity in 2010. The difference between median and best practice is reasonably consistent from 2003 – 2006 with the difference growing from 30% in 2003 to 45% in 2006. Since 2007 there has been a major shift in the relative performance of median and best practice. Best practice is between 100% and 125% higher than median since 2007.

Figure 12 is a plot showing the differences between Australian rope shovel median performance and those in South Africa, North America and South America. Results have been normalised for split between coal and non-coal performance.

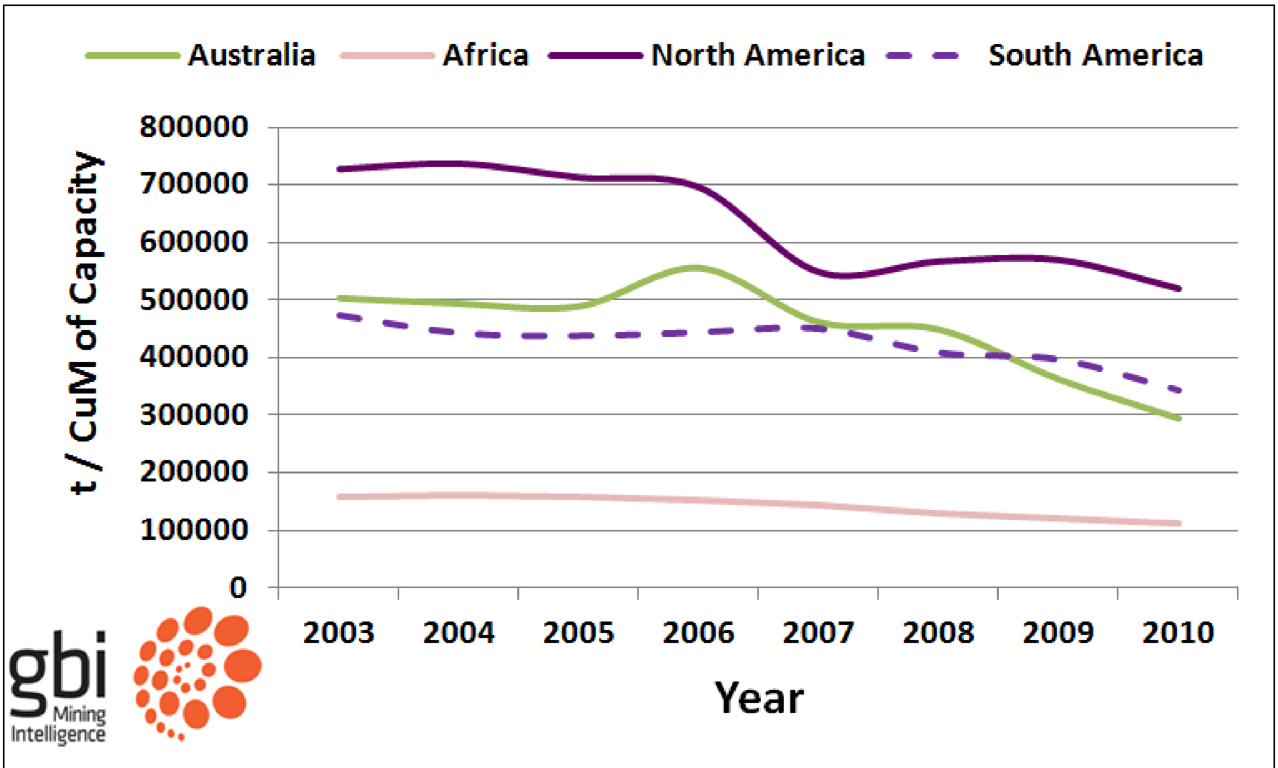

Figure 12. Worldwide Rope Shovel Median Annual Unit Production (t/CuM of capacity) 2003-2010 by Continent

All countries demonstrate the same trend with the general decline in equipment performance being evident. North America has the highest annual output with Africa the lowest. Australia and South America are in between with Australia generally being above South America except for 2009-2010. The declines from the peak to 2010 are as follows; Australia 47%, South Africa 31%, North America 30% and South America 28%.

Figure 13 is the plot of difference between states in Australia. Rope shovels are predominantly used in NSW and Queensland.

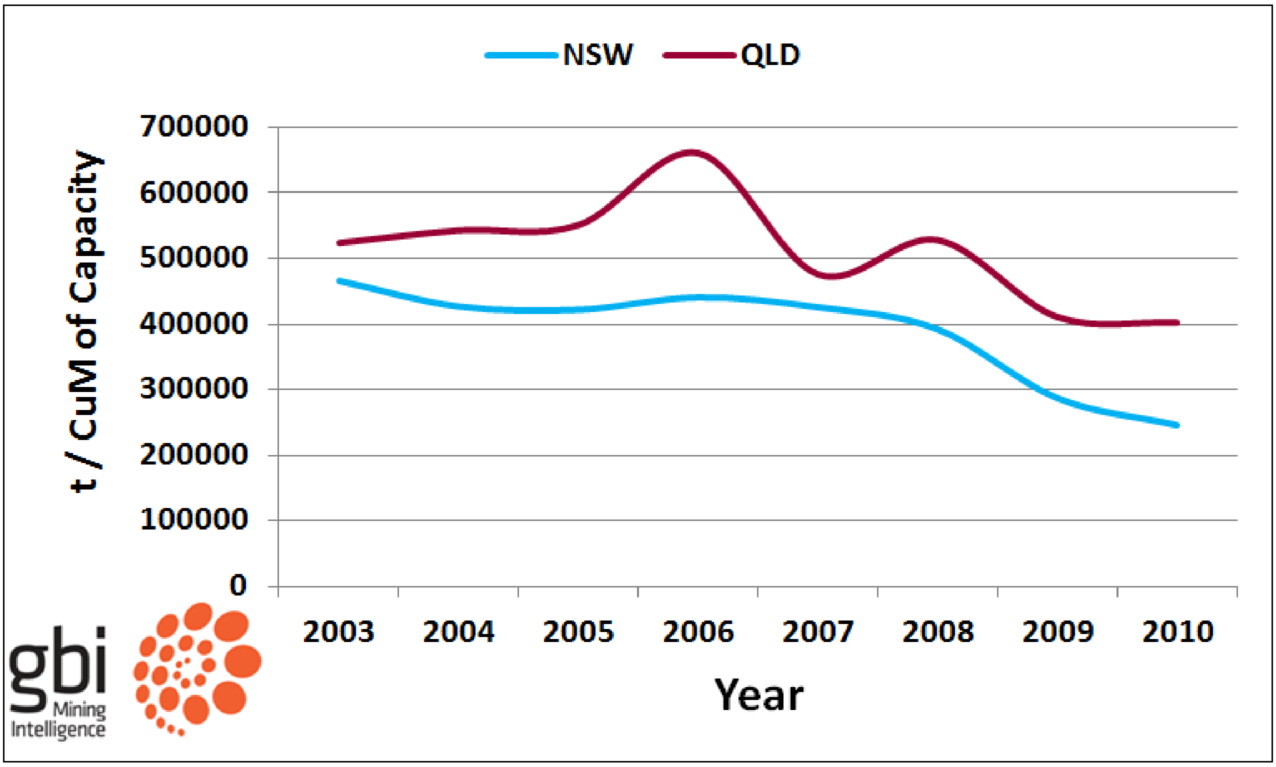

Figure 13. Australian Rope Shovel Median Annual Unit Production (t/CuM of capacity) 2003-2010 by State

Queensland had a peak in performance in 2006 followed by a 39% decline to 2010. NSW's decline from 2003 to 2010 is greater at 47%. All states have seen a significant decline over the last 2-4 years. NSW has tended to underperform Queensland from 2003 - 2010.

Figure 14 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.

The same general trends can be seen in coal and non-coal with a few variations. The performance of electric rope shovels in coal mines is higher than in non-coal mines. In percentage terms the decline in median annual output for non-coal mines (57%) is greater than the coal mines (42%).

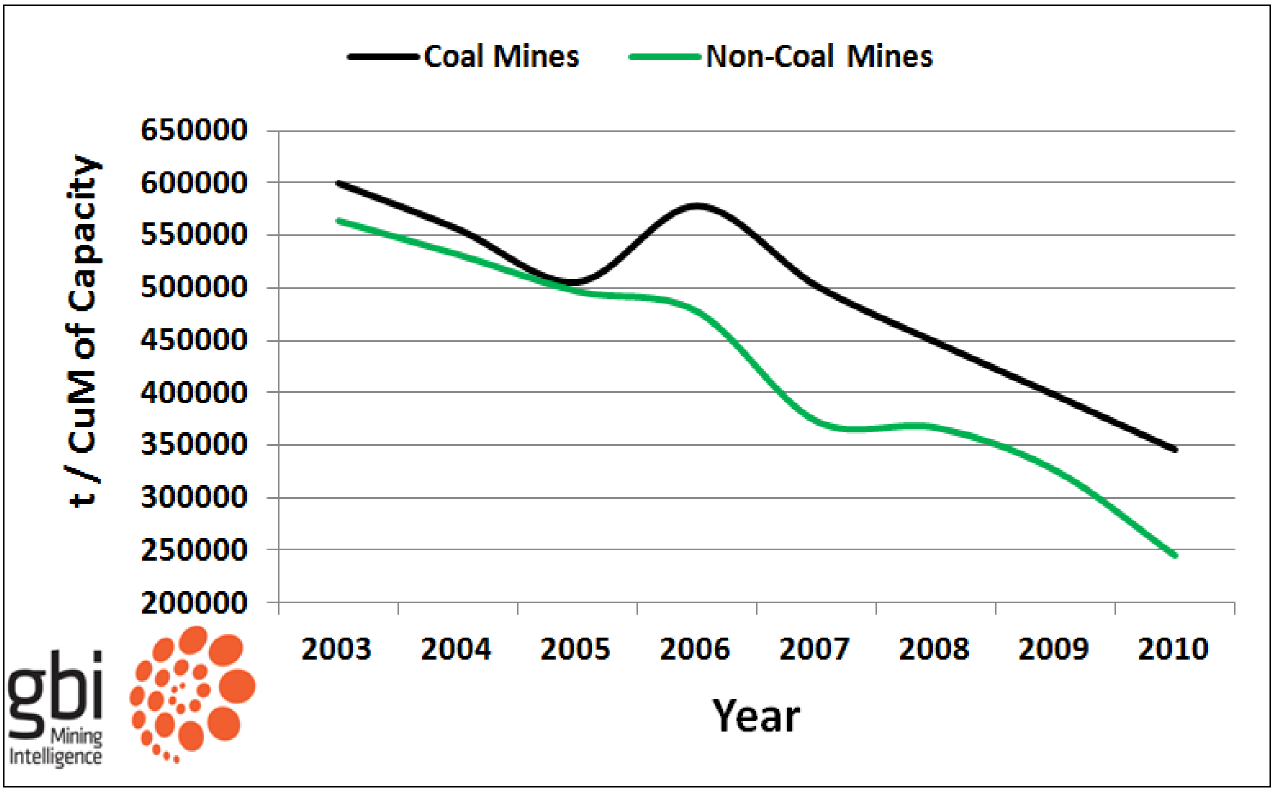

Figure 14. Worldwide Rope Shovel Median Annual Unit Production (t/CuM of Bucket Capacity) 2003-2010 Coal vs Non-Coal

The final comparison is by make and model. Figure 15 shows the 2010 median performance for each make and model.

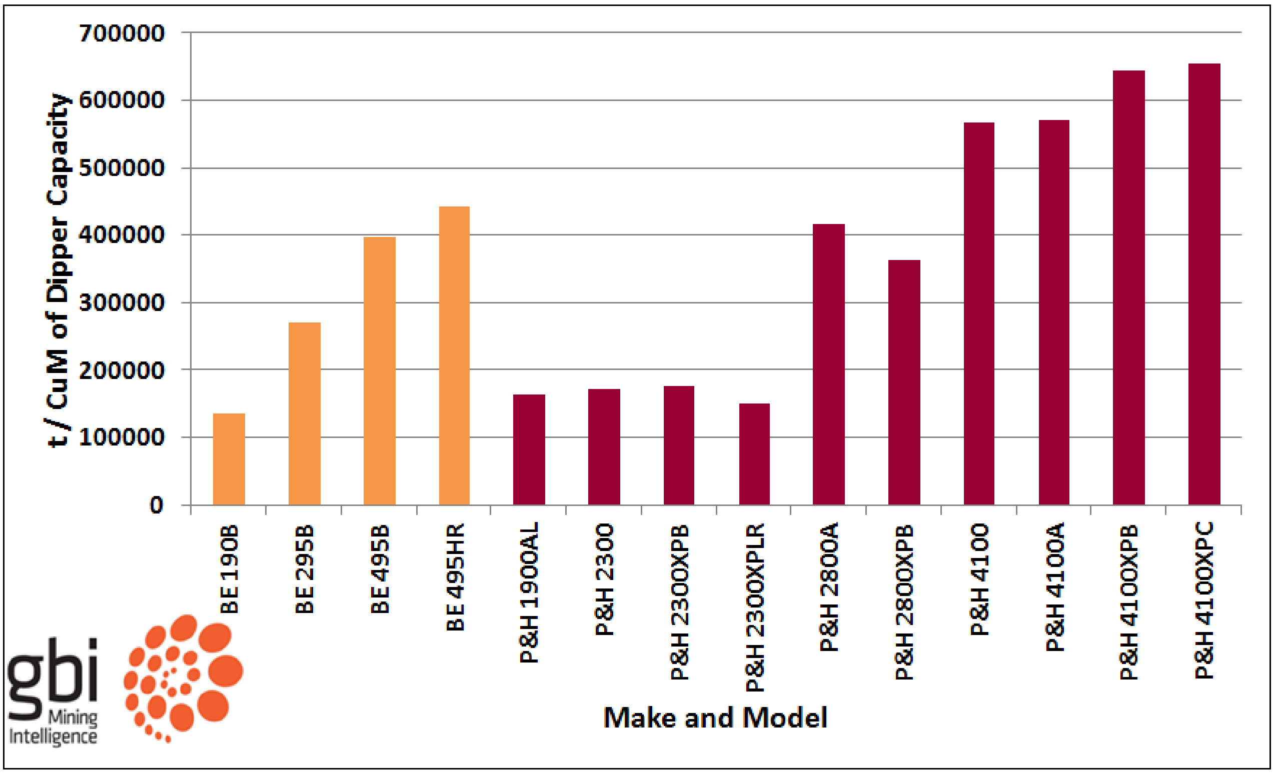

Figure 15. Rope Shovel Annual Unit Production (BCM/t of RSL) 2010 by Make and Model

It is important to note that, as was the case with the dragline comparison, this plot does not attempt to say whether the make and model results actually reflect better shovels or the operating characteristics of the sites at which they are used. The P&H shovels tend to have higher annual output than the BE (now Cat) shovels.

There is an interesting characteristic of this graph which is worth noting. The unit capacity increases with increasing machine size. This is not the same as draglines where a number of the larger draglines have lower annual unit output. Bigger machines move more than smaller machines even after the results are modified to normalise differences in the capacity of the dipper.

Hydraulic Excavators

Hydraulic excavators have had widespread use in the non-coal sectors over a number of decades but have increasingly been employed at coal mines during the last 10 years. Capacities range up to the 750+ tonne class machines which can have 40 + CuM capacity buckets. Most current excavators are in the 12 - 32 CuM capacity range. They are more flexible than a dragline and a shovel due to them running on diesel and not being constrained by the electricity cable. However, they are generally more expensive to operate on a per unit basis and do not move as much as a dragline nor a rope shovel. While being a predominant source of stripping capacity in iron ore mines and other hard rock applications in Australia for a number of years, many existing and new coal mines are choosing hydraulic excavators for their additional or replacement capacity. Hydraulic excavators are predominantly used by contractors due to their flexibility. An hydraulic excavator set up in face shovel configuration is shown in Figure 16 while the hydraulic excavator set up as backhoe configuration is shown in Figure 17. Hydraulic excavators are measured on annual tonnes (normalised for full year operation) per cubic metre of bucket capacity.

Figure 16. Hydraulic Excavator Set Up as Face Shovel

Figure 17. Hydraulic Excavator Set Up as Backhoe

Data pre-2003 is again not of sufficient quantity and quality to provide a valid comparison. The 2003 - 2010 performance is shown in Figure 18 and demonstrates significant changes over this period.

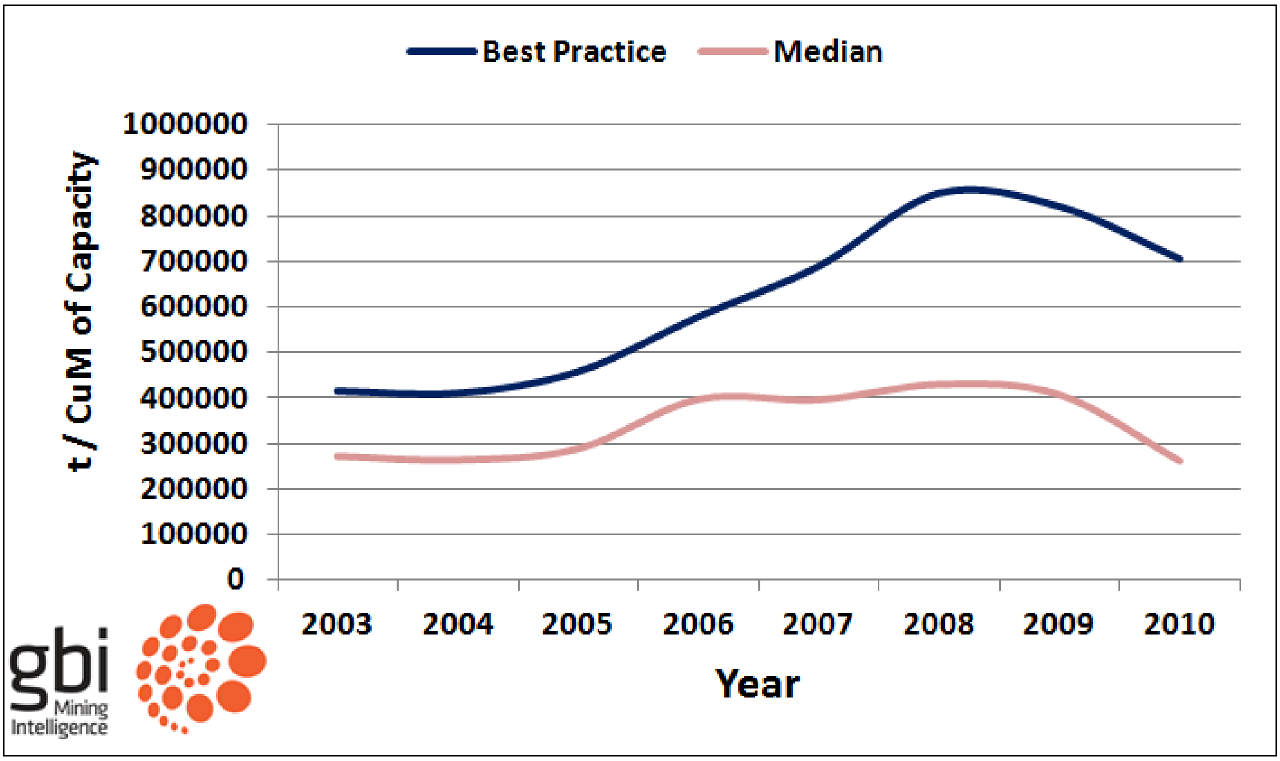

Figure 18. The median performance rises from Worldwide Hydraulic Excavator Annual Unit Production (t/CuM of Capacity) 2003-2010 by Performance

Median hydraulic excavator annual output increased from 265 000 tonnes per cubic metre of bucket capacity in 2004 to 435 000 tonnes per cubic metre of bucket capacity in 2008; a rise of 64% in 5 years. Best practice performance rose in a more dramatic fashion from 410 000 tonnes per cubic metre of bucket capacity to 850 000 tonnes per cubic metre of bucket capacity; a rise of 107% in five years. The peak levels (achieved in 2008) have not been maintained and have fallen 17% and 39% for best practice and median respectively in two years. The difference between median and best practice has become more pronounced; rising from around 50% in 2003-05 up to 136% in 2010.

Figure 19 is a plot showing the differences between Australian excavator median performance and those in South Africa, North America, South America and Asia. Results have been normalised for split between coal and non-coal performance.

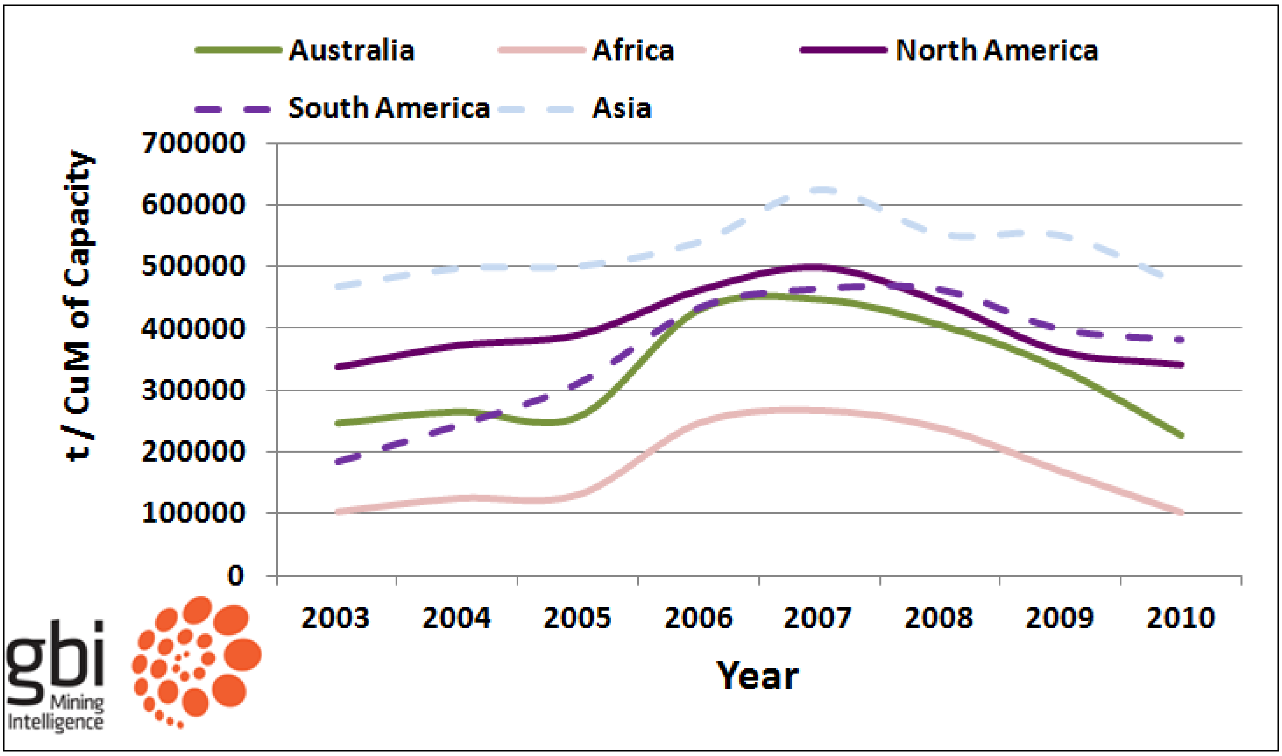

Figure 19. Worldwide Excavator Median Annual Unit Production (t/CuM of Capacity) 2003-2010 by Continent

All countries demonstrate the same general trend with the peak around 2006-2008 being evident. Asia reports the highest excavator performance with Africa being the lowest. Australia is generally the next lowest, however, Australia, South America and North America are reasonably similar. All continents have a decline of between 18% in South America and 69% in South Africa. Australia had a decline of 49% from the peak in 2006 to 2010.

Figure 20 is the plot of difference between states in Australia. Sufficient data to provide statistical relevancy prior to 2005 in WA and 2006 in NSW is not available.

Queensland had a peak in performance in 2006 – 2007. WA experienced a peak in 2007. All states have seen a significant decline over the last 2-4 years with WA down 32%, Queensland down 45% and NSW down 51%. NSW has tended to underperform Queensland and WA although prior to 2006 is unclear.

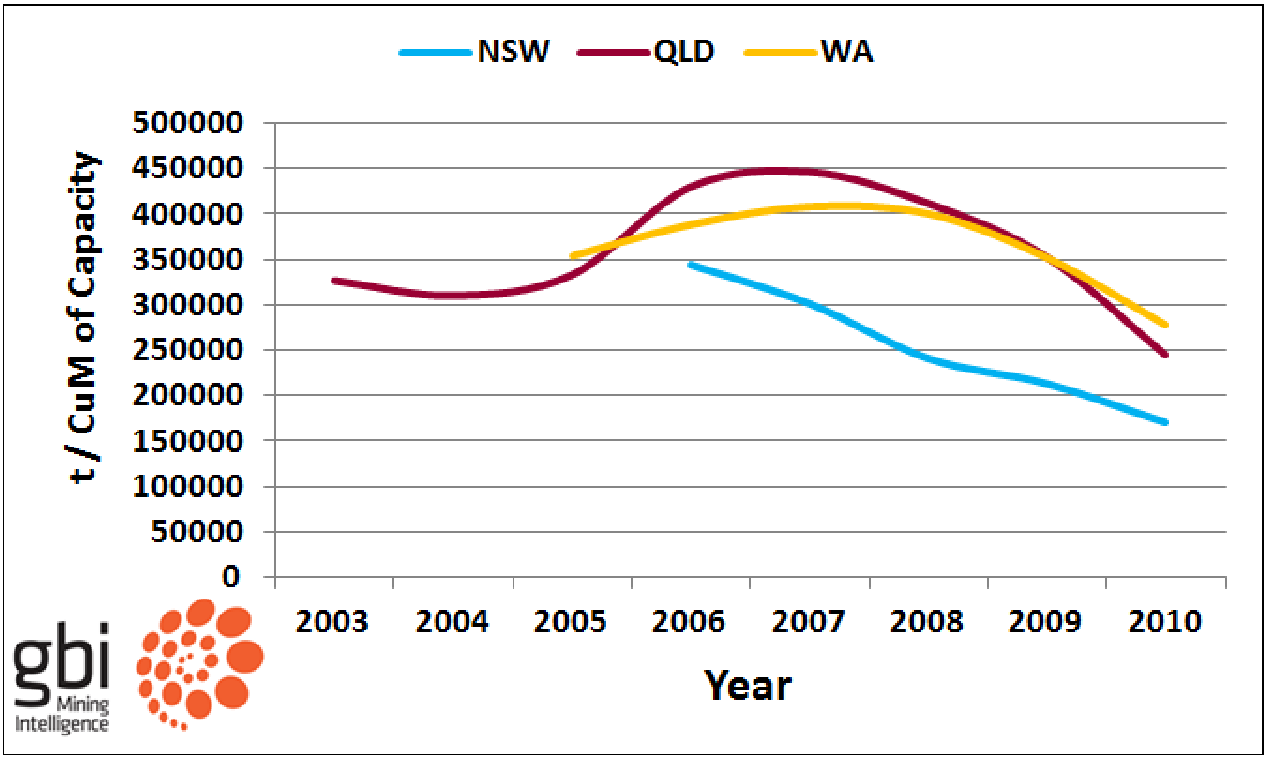

Figure 20. Australian Excavator Median Annual Unit Production (t/CuM of Capacity) 2003-2010 by State

Figure 21 is a plot showing the differences between the performance of hydraulic excavators 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 individual commodity.

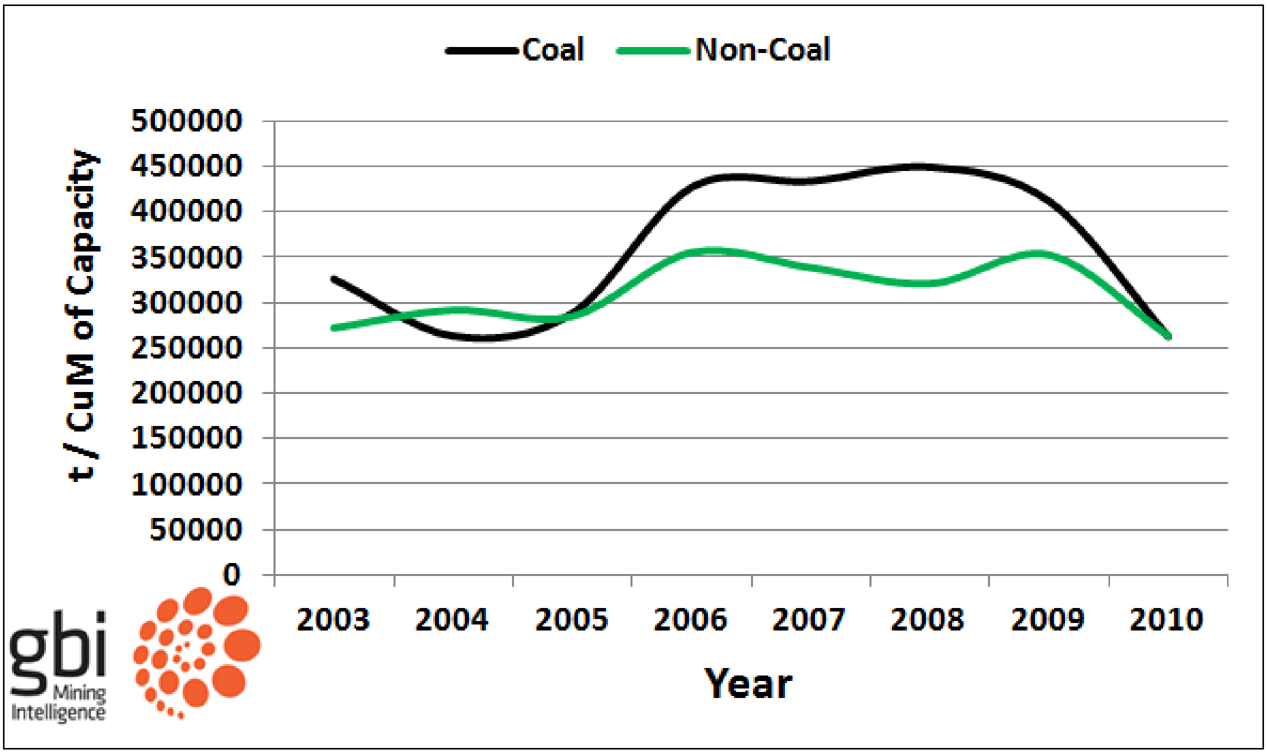

Figure 21. Worldwide Hydraulic Excavator Annual Unit Production (t/CuM of Capacity) 2003-2010 Coal vs Non-Coal

The same general trends can be seen in coal and non-coal with a few variations. Performance in coal mines between 2006 and 2009 was between 20% and 40% better than non-coal mine performance. Pre 2006 and post 2009 the performance was similar. The decline from the peak to 2010 is also evident.

Figure 22 is a further comparison between hydraulic excavators set up as backhoe configuration and those set up in face shovel configuration.

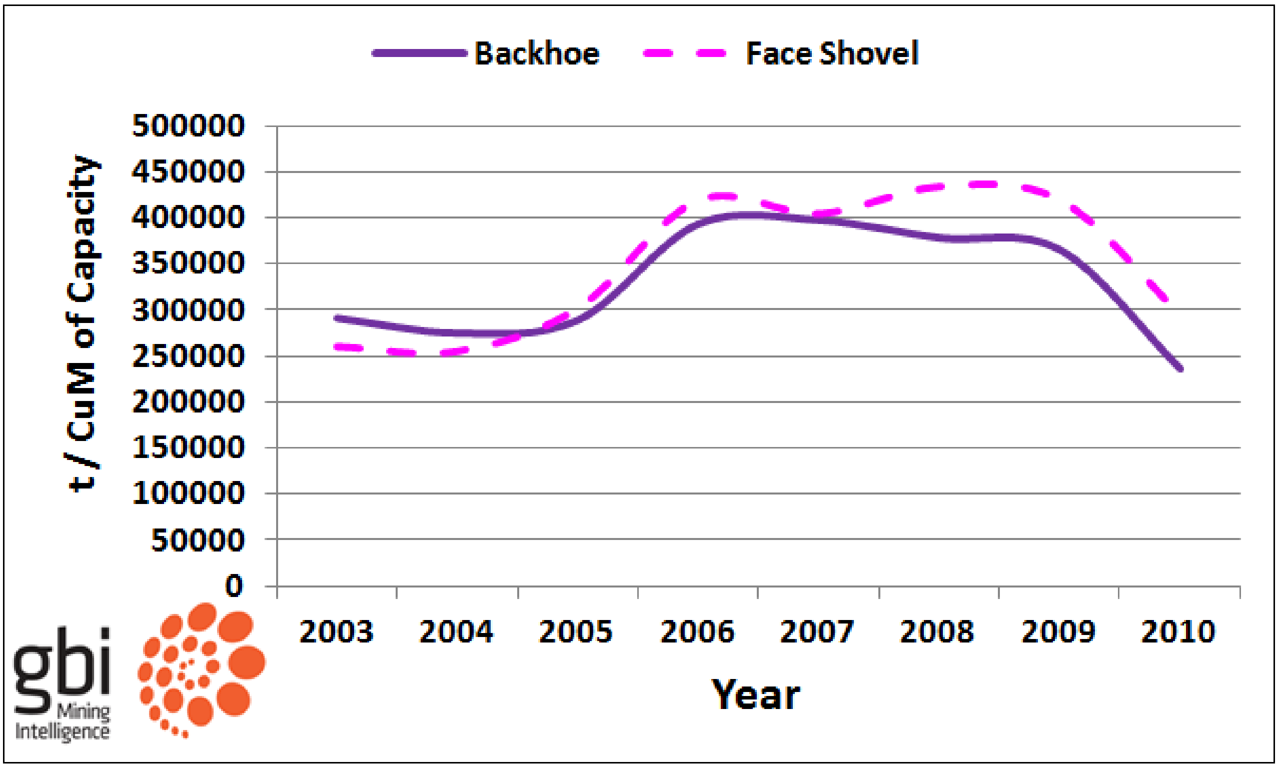

Figure 22. Worldwide Hydraulic Excavator Annual Unit Production (t/CuM of Capacity) 2003-2010 Configuration

In more recent years the performance of the face shovel configuration has provided more annual output for the median performance than for backhoe configuration. The decline into 2010 is consistent between set-ups with face shovel configuration being down 32% and backhoe configuration being down by 41%. These declines are consistent with what has been recorded by a large number of pieces of equipment; excavators and other.

The final comparison is by make and model. Figure 23 shows the 2010 median performance for each make and model.

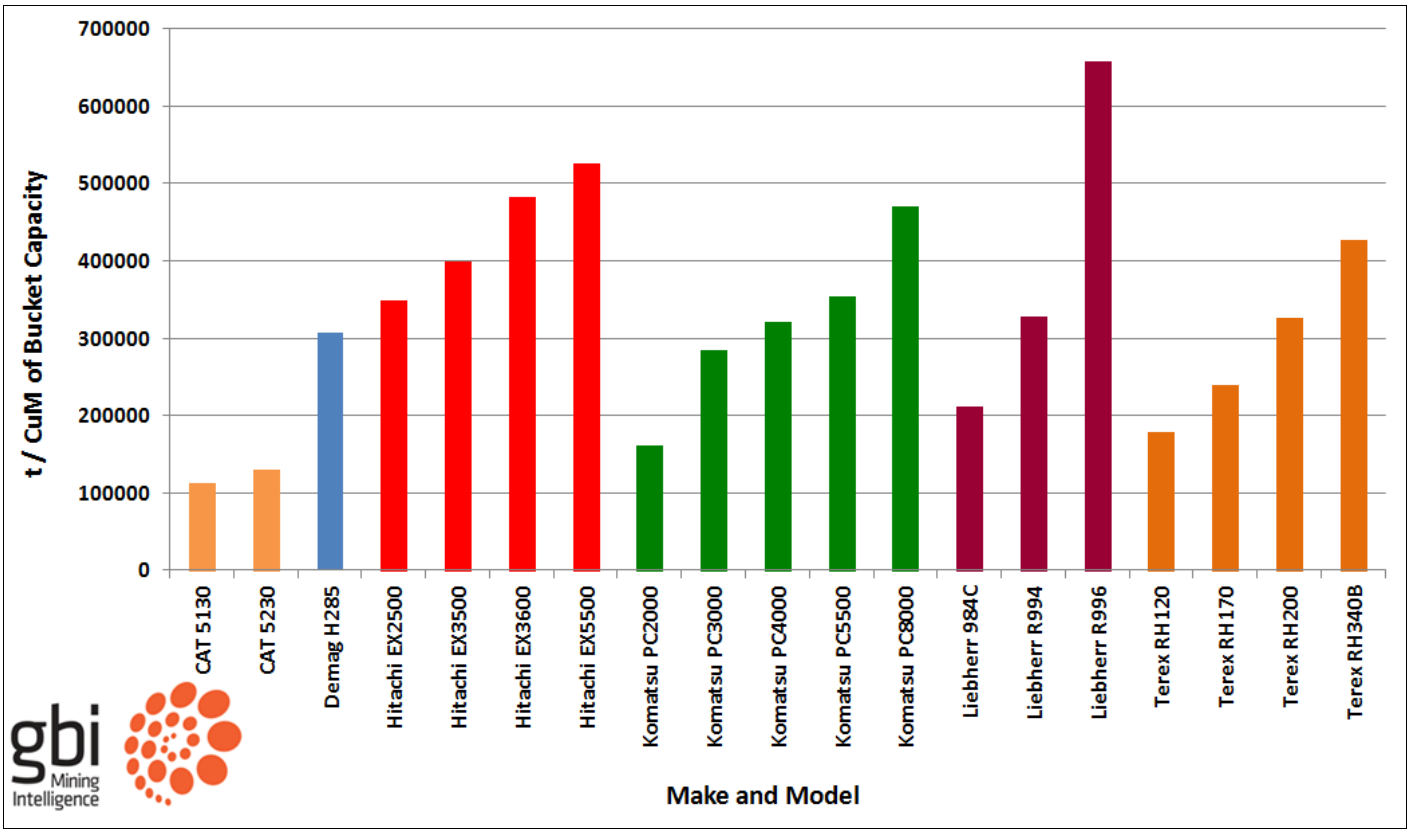

Figure 23. Hydraulic Excavator Annual Unit Production (t/CuM of Bucket Capacity) 2010 by Make and Model

It is important to note that this plot does not attempt to say whether the make and model results actually reflect better machines or the operating characteristics of the sites at which they are used. It also doesn't distinguish between shovel arrangement and backhoe arrangement. As was the case with electric rope shovels, larger equipment is proving to be more efficient than smaller equipment. There are significant differences between different makes of excavator. By way of example, the Liebherr R996 median annual output per cubic metre of bucket capacity is 86% higher than the Komatsu PC5500, 54% higher than the Terex 340B (now Cat 6090), and 25% higher than the Hitachi EX5500. Each of these excavators are a similar operating weight.

Front End Loaders

A front end loader (also known as: bucket loader, front loader, payloader, scoop loader, shovel, skip loader, and/or wheel loader) is a type of tractor, usually wheeled, that has a front mounted square wide bucket connected to the end of two booms (arms) to scoop up material from the ground and move it from one place to another (usually a mining truck) without pushing the material across the ground.

The largest front end loader in the world is LeTourneau L2350. The L2350 uses a diesel electric propulsion system. Each rubber tired wheel is driven by its own independent electric motor. Front end loaders (FEL's), have had widespread use in the mining industry (both coal and non-coal) over a number of decades both as primary stripping tools and as ancillary support equipment. Capacities range up to the LeTorneau L2350 which can utilise a 40 + CuM capacity bucket. Most current FEL's are in the 12 - 30 CuM capacity range. They are more flexible than any other loading tool but can have height limitations with the larger mining trucks. FEL's are generally more expensive to operate on a per unit basis and do not move as much as other loading tools. FEL's are measured on annual tonnes (normalised for full year operation) per cubic metre of bucket capacity.

Figure 24. Front End Loader

The 2003 - 2010 median and best practice performance is shown in Figure 25 and demonstrates significant changes over this period.

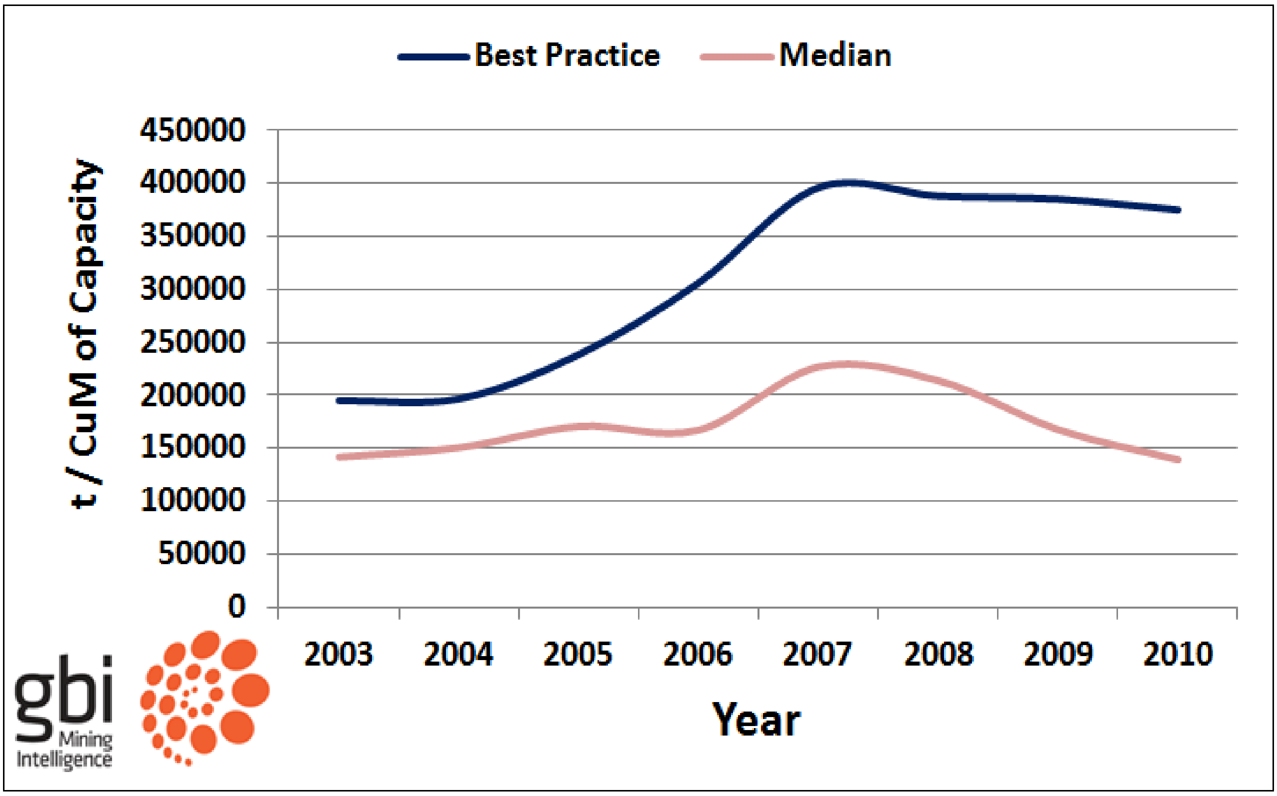

Figure 25. Worldwide FEL Annual Unit Production (t/CuM of Capacity) 2003-2010 by Performance

The median performance rises from 142 000 tonnes per cubic metre of bucket capacity in 2003 to 227 000 tonnes per cubic metre of bucket capacity in 2007; a rise of 60% in 5 years. As has been shown with other classes of equipment, best practice performance rises in a more dramatic fashion from 196 000 tonnes per cubic metre of bucket capacity to 396 000 tonnes per cubic metre of bucket capacity; a rise of 102% in five years. As has happened with other classes of loading units, performance has fallen over the last few years. Best practice and median FEL peak levels have fallen 5% and 39% respectively over the last three years. Best practice is being maintained at a relatively high level while median annual output has fallen significantly. The difference between median and best practice rose consistently from 31% in 2004 to 169% in 2010.

Figure 26 is a plot showing the differences between Australian excavator median performance and those in South Africa, North America, South America and Asia. Results have been normalised for the split between coal and non-coal performance.

All countries demonstrate the same general trend as with other loading units with the peak around 2006-2008 being evident.

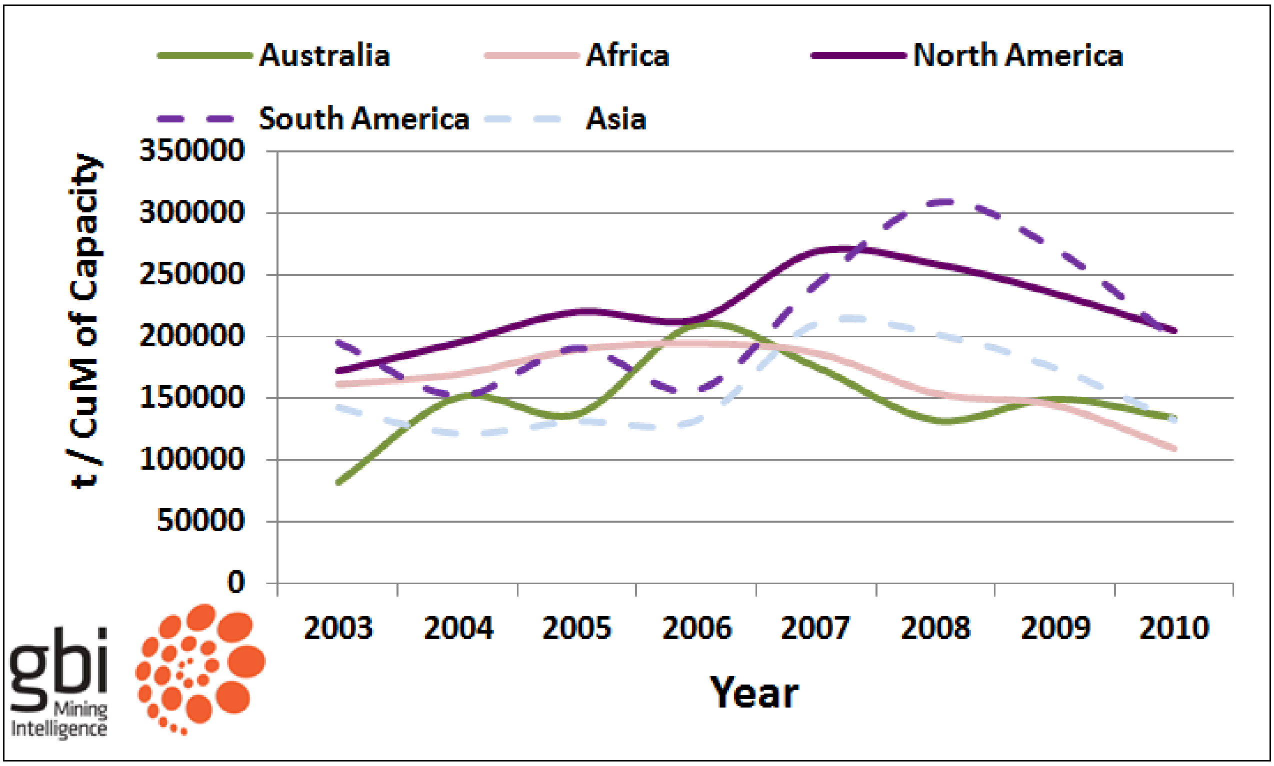

Figure 26. FEL Median Annual Unit Production(t/CuM of capacity) 2003-2010 by Continent

Figure 27 is the plot of difference between states in Australia. Sufficient data to provide statistical relevancy prior to 2005 in WA and 2006 in NSW is not available.

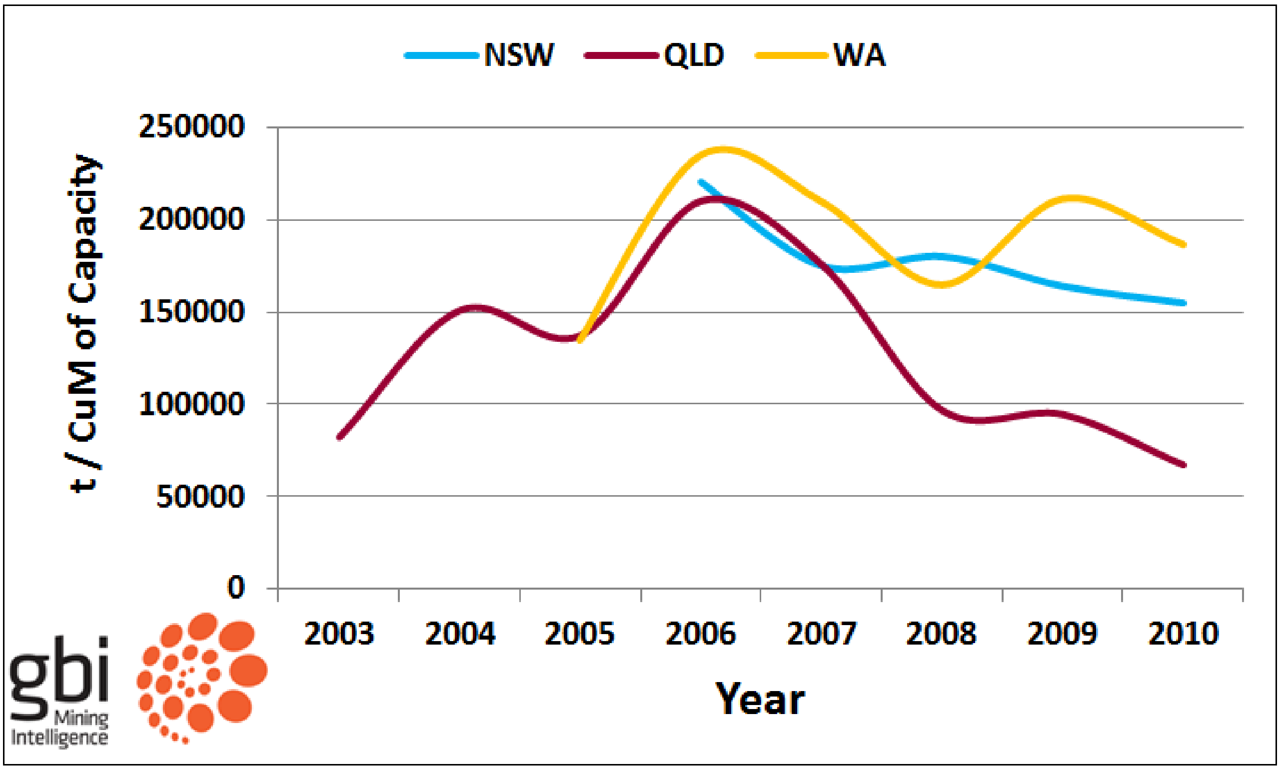

Figure 27. FEL Median Annual Unit Production (t/CuM of capacity) 2003-2010 by State

All states had a peak in performance in 2006. All states have seen a significant decline over the last 2-4 years although these results are more variable than other types of loaders. Queensland has tended to underperform NSW and WA.

Figure 28 is a plot showing the differences between the performance of FEL's 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 individual commodity.

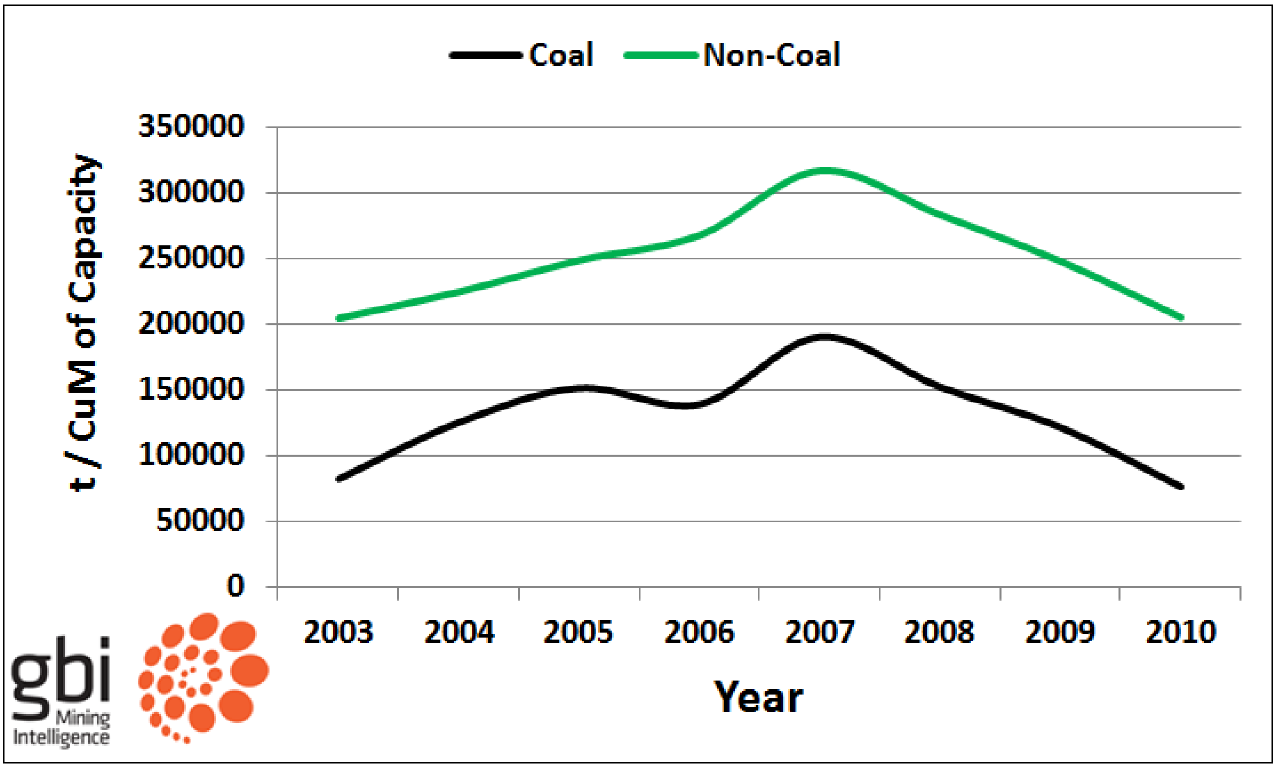

Figure 28. Worldwide FEL Median Annual Unit Production (BCM/t of RSL) 2003-2010 Coal vs Non-Coal

The same general trends can be seen in coal and non-coal with a few variations. Performance in non-coal mines was significantly better than coal mines. The difference peaked in 2010 at 170%. Non-coal mines declined in unit annual output by 36% between 2007 and 2010, however the decline in coal mines during this time was 60%.

The final comparison is by make and model. Figure 29 shows the 2010 median performance for each FEL make and model.

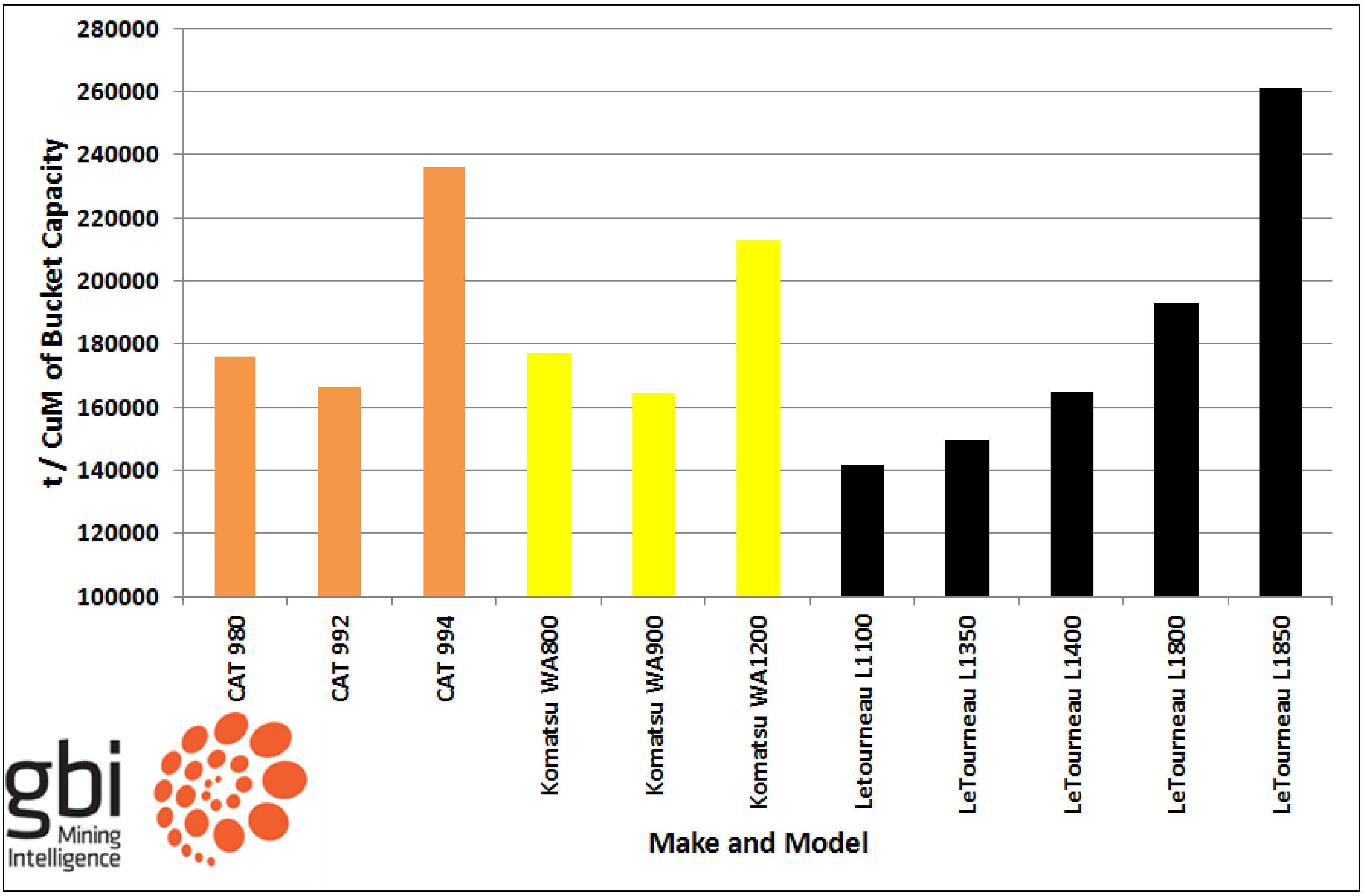

Figure 29. FEL Annual Unit Production (t/CuM of Bucket Capacity) 2010 by Make and Model

The different designations (usually A, B, etc used by Cat) have not been separated in this analysis. The capacities are generally similar as is the output. It is important to note that this plot does not attempt to say whether the make and model results actually reflect better machines or the operating characteristics of the sites at which they are used. It also doesn't distinguish between shovel arrangement and backhoe arrangement. As was the case with electric rope shovels and hydraulic excavators, larger equipment is proving to be more efficient than smaller equipment. There are significant differences between different makes of excavator. The LeTorneau L1850 and Cat994 are the top performing FEL's.

Mining Trucks

Mining trucks generally have a rigid frame and conventional steering with drive at the rear wheel. The largest are the Liebherr T 282C, the Bucyrus/Terex MT6300AC and the Caterpillar 797F, which each have payload capacities of up to 400 imperial / short tons (363 metric tonnes). Most large size haul trucks employ diesel/electric powertrains, using the diesel engine to drive an AC alternator or DC generator that sends electric power to electric motors at each rear wheel. The large Caterpillar trucks are different as they employ a diesel engine to power a mechanical powertrain. Other major manufacturers of haul trucks include Hitachi, Komatsu and Terex (now owned by Cat). A large mining truck is shown in Figure 30.

Figure 30. Mining Haul Truck

Mining truck performance is presented in this paper as annual tonnes (normalised for full year operation) * km travelled per tonne of nominal tray carrying capacity.

The 2002 - 2010 median and best practice performance is shown in Figure 31 and demonstrates significant changes over this period.

The median performance rises from 541M tonnekm per tonne of nominal truck capacity in 2002 to 1412 tonnekm per tonne of nominal truck capacity in 2006; a rise of 161% in 4 years. Best practice performance rises more in absolute terms but not as much in percentage terms. Best practice rises from 1473M tonnekm per tonne of nominal truck capacity in 2002 to 2883 tonnekm per tonne of nominal truck capacity in 2006; a rise of 96% in 4 years.. As has happened with other classes of loading units, performance has fallen over the last few years. Best practice and median FEL peak levels have fallen 44% and 41% respectively over the last four years. The difference between median and best practice varied from 75% in 2004 to 171% in 2002. From 2008 to 2010 the best practice was consistently 100% – 110% better than the median.

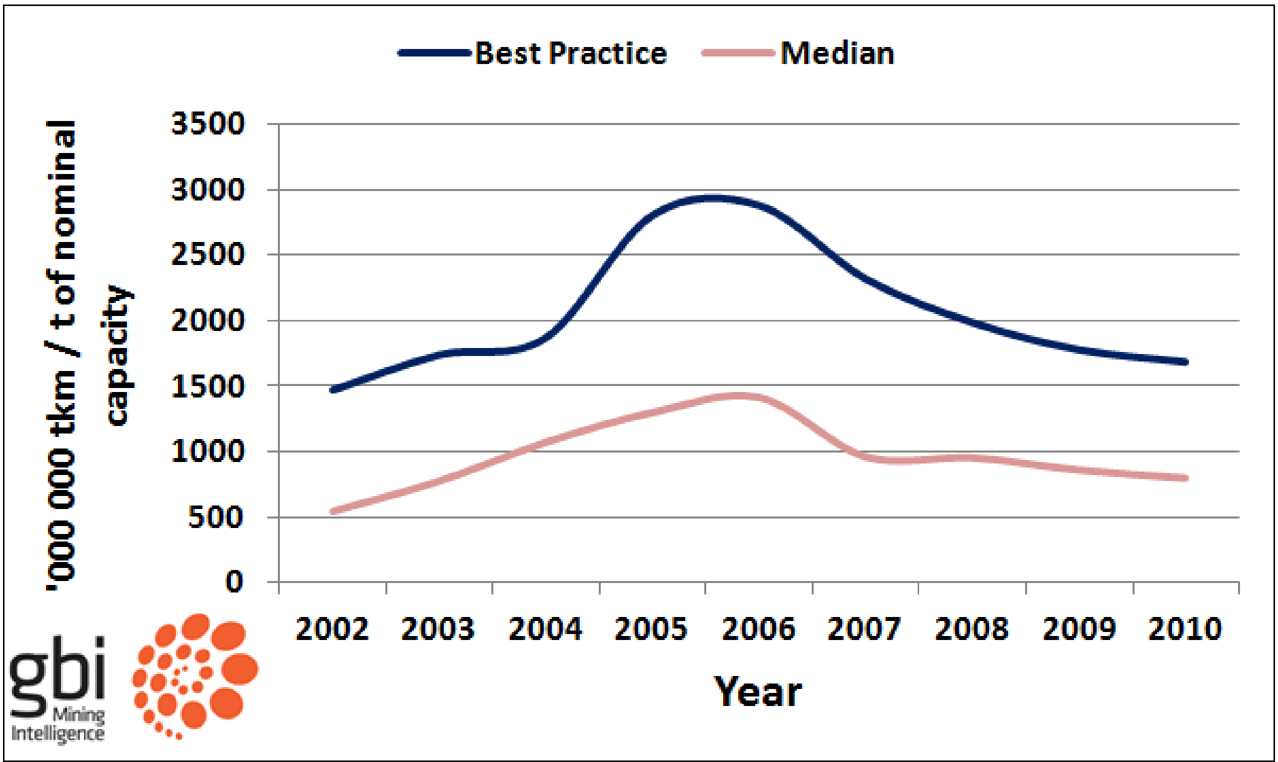

Figure 31. Worldwide Mining Truck Annual Unit Production (tkm /t of Nominal Capacity) 2002-2010 by Performance

Figure 32 is a plot showing the differences between Australian excavator median performance and those in South Africa, North America, South America and Asia. Results have been normalised for split between coal and non-coal performance.

All countries demonstrate the same general trend as with other loading units with the peak around 2005-2007 being evident.

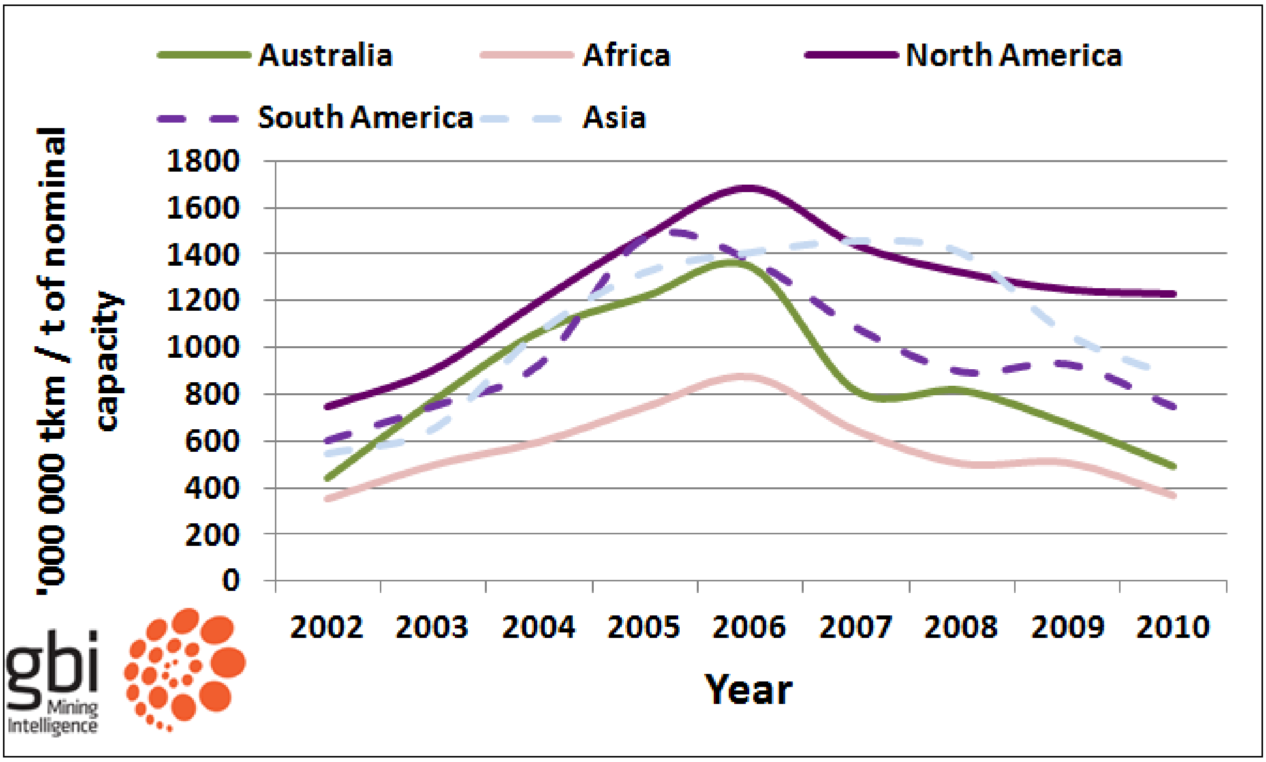

Figure 32. Mining Truck Median Annual Unit Production (tkm/t of Nominal Capacity) 2002-2010 by Continent

Figure 33 is the plot of difference between states in Australia. Sufficient data to provide statistical relevancy prior to 2005 in WA and NSW is not available.

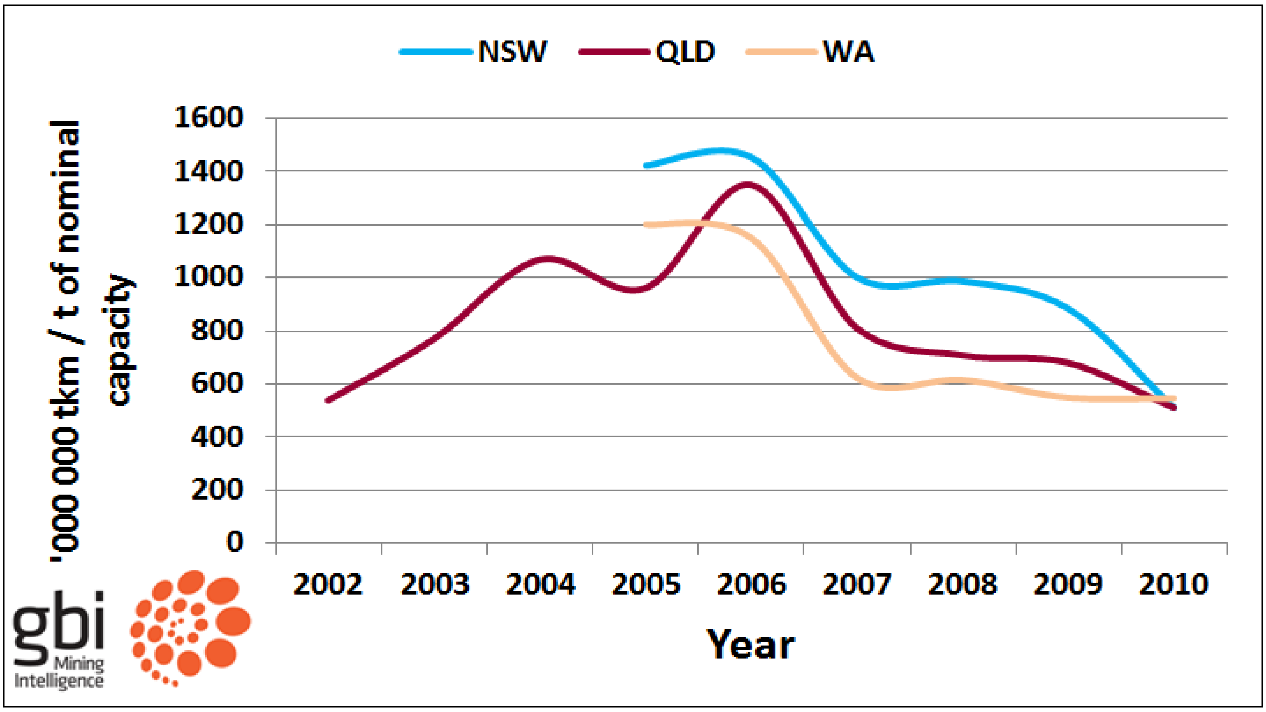

Figure 33. Mining Truck Median Annual Unit Production (tkm/t of Nominal Capacity) 2002-2010 by State

All states had a peak in performance in 2006. All states have seen a significant decline from 2007 to 2010. Performance across all states is consistent in 2010. Prior to 2009 NSW obtained higher annual output than Queensland or Western Australia.

Figure 34 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 individual commodity.

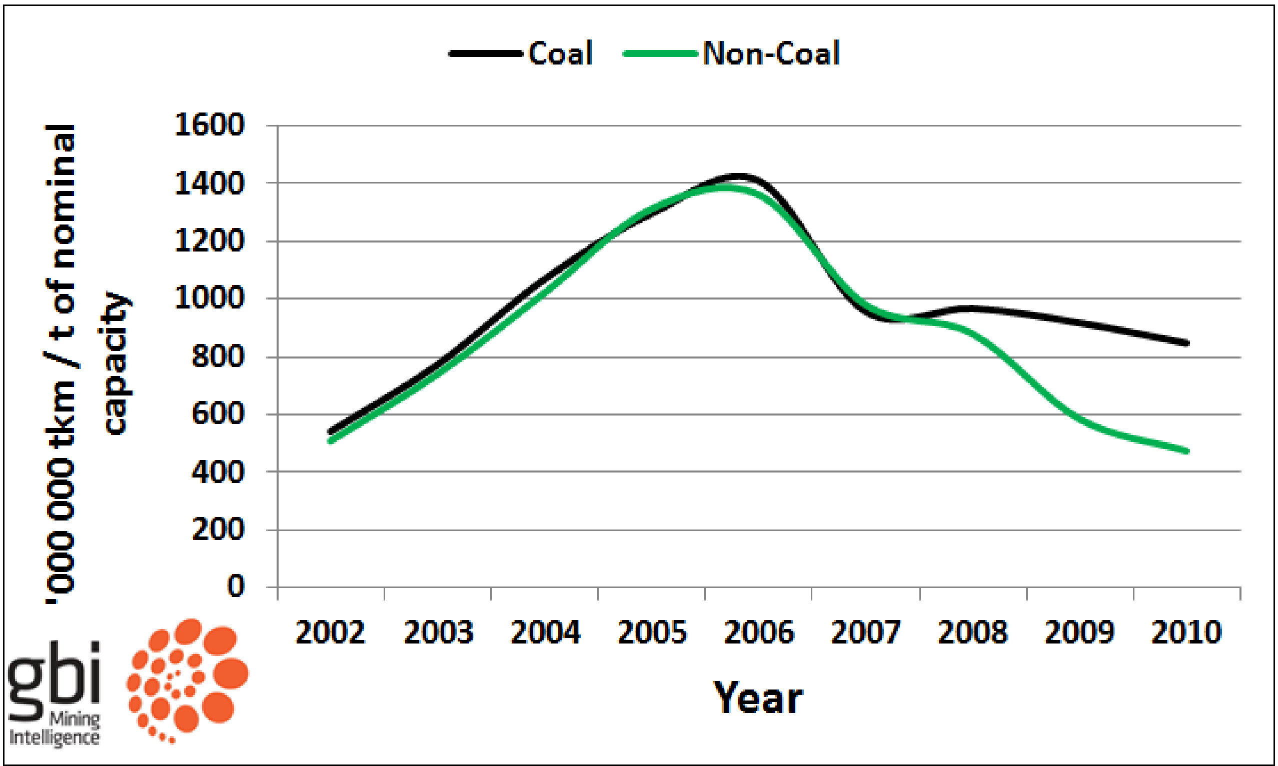

Figure 34. Worldwide Mining Truck Median Annual Unit Production (tkm/t of Nominal Capacity) 2002-2010 Coal vs Non-Coal

The same general trends can be seen in coal and non-coal with a few variations. The most significant observation is the significant decline in non-coal truck unit output from 2008 – 2010. During this time the non-coal mine mining trucks dropped by 46% while those used on coal mines dropped by only 12%.

The final comparison is by make and model. Figure 35 shows the 2010 median performance for each major mining truck make and model. Some of the older and newer models are not included due to lack of data.

Trucks with different designations (usually A, B, etc used by Cat and Liebherr) have not been separated in this analysis. The capacities for these “sub-models” are generally similar as is the output. It is important to note that this plot does not attempt to say whether the make and model results actually reflect better trucks or the operating characteristics of the sites at which they are used. The trends with increasing size of mining trucks appears to be mixed. The Liebherr trucks become more efficient with increasing size while the Cat trucks become less efficient with increasing size. The Komatsu and Terex trucks achieve peak efficiency with the 240 ton (218 metric tonne) capacity size 830E and 4400 respectively. The larger capacity trucks are not as efficient with these two makes. Of the larger trucks the Liebherr T282 is the highest performer with Terex and Komatsu both achieving 20% less annual tkm/t and Cat 23% less annual tkm/t.

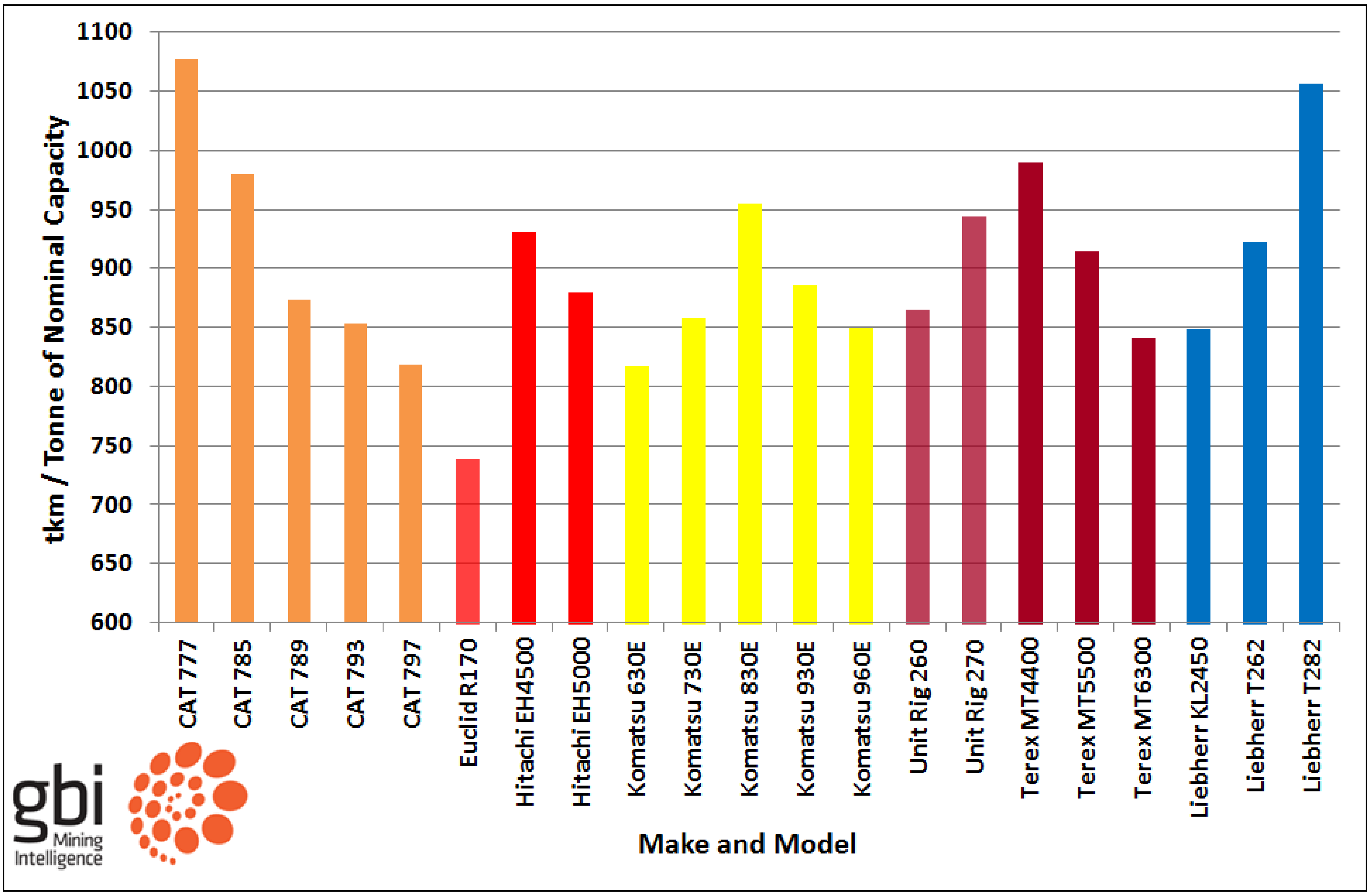

Figure 34. Mining Truck Annual Unit Production (tkm/t of Nominal Capacity) 2010 by Make and Model

CONCLUSION

This information provides an account of the performance of open cut mining equipment from the first use of production monitors and should be extended in years to come to determine where this industry is heading with efficiency. In 2010 the picture is not great in Australia, nor the worldwide industry, with all equipment and the whole of mines reducing performance significantly over the last 2-9 years.

A number of significant insights can be gained from the Australian Bureau of Statistic's Multifactor Productivity measure;

1. There was a substantial rise in productivity in the mining sector from 1986-87 to 2000-01. The MFP rose from 92.6% to 146.0% of 1985-86 productivity (a rise of 58%) during this 14 year period.
2. There was a decline in productivity in the mining sector from 2000-01 to 2009-10. In fact almost all the gains from 1986-87 were wiped out during this time leaving the industry performing at the same levels in 2009-10 as they were in 1986-87.
3. The performance of the 12 select industries shows a 20% gain over the same time frame

Based on the most recently available operating data current open cut mining annual output has declined significantly over the last 2-9 years. Median dragline annual output per tonne of RSL peaked in 2003 and has declined 15% to 2010. Median rope shovel performance peaked in 2003 and declined 41% by 2010. Mining truck median performance peaked in 2006 and has declined 41% by 2010. Loading equipment annual output peaked later with front end loaders in 2007 and hydraulic excavators in 2008. In both these cases the performance has dropped 39% to 2010 from the peak.

Best practice machines (the average of the top 10%) are also declining but not generally as much as the median. Best practice dragline annual output has declined by 13%, rope shovels by 8%, excavators by 17% and FEL's by 5% from their peak year. Mining trucks are the only class of mining equipment where best practice has declined more than median with 2010 median performance having declined 44% since 2006. Consequently, in 2010 the difference between best practice, (theoretically what the class of equipment is capable of), and median, (representing collectively what the industry is doing with the class of equipment) has grown to large numbers. For draglines the best practice annual output in 2010 was 33% higher than median compared with 26% in 2003. For rope shovels the best practice annual output in 2010 was 125% higher than median compared with 32% in 2003. For excavators the results were 168% in 2010 compared with 45% in 2006 and FEL's were 169% in 2010 compared with 31% in 2004. Best practice mining trucks are 112% more productive than median (cf. 142% in 2006).

Australia is not best in class for any piece of equipment. Australia is below the annual output of North America and above Africa (except for FEL's) across all classes of equipment. Australian annual output relative to Asia and South America is generally (but not universally) lower.

Apart from draglines there is apparently increasing unit annual output (t/CuM of capacity) as machine capacity increases indicating an increase in efficiency with larger (newer?) machines. Consequently, there continues to be significant advantages in efficiency in choosing larger equipment. With draglines there is some evidence that the larger equipment is still proving problematic with respect to annual output with the BE2570WS and M8750/M8200S both achieving less unit annual output than smaller models from each supplier. Mining trucks also show different trends for different manufacturers. The Liebherr trucks become more efficient with increasing size while the Cat trucks become less efficient with increasing size. The Komatsu and Terex trucks achieve peak efficiency with the 240t capacity size 830E and 4400 respectively. The larger capacity trucks are not as efficient with these two makes. Of the larger trucks the Liebherr T282 are the highest performer with Terex and Komatsu achieving 20% less and Cat 23% less output .

There remains significant difference between median performance between different manufacturers and models. By way of example, in excavators the Liebherr R996 median annual output per cubic metre of bucket capacity is 86% higher than the Komatsu PC5500, 54% higher than the Terex 340B (now Cat 6090), and 25% higher than the Hitachi EX5500. Again, reasons for these differences have not been investigated. This paper simply states that across a statistically valid number of loading units the median performance of the Liebherr was significantly better than the other makes and models.

The difference between coal mines and non-coal mines varies and seems to depend on what is being dug. Generally rope shovels and excavators have higher median annual output per unit of capacity for machines in coal mines compared with non-coal mines while the difference is reversed for FEL's. The results for mining trucks were consistent until 2008 when output for the non-coal mines trucks started falling at a significant rate.

This paper concludes by stating what was in the introduction. The analysis has not sought to paint any particular picture nor has it biased the actual data in any way. While making comment on the trends, this paper has not sought to interpret the factors which have led to the trends. It is expected that others may be able to prepare discourses on the reasons for the trends and ways of learning from the information contained herein. The challenge is what to do about the trends in efficiency both as an industry; as individual mines; and as individual people working in this industry.

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