Introduction

Best practice mines deliver their corporate goals by efficiently and effectively implementing their mine plan. From the authors’ experience, these best practice mines have the following similarities:

• Sound mine planning and mine operational practices
• Appropriate equipment and manning levels
• Good information collection and reporting
• A continuous improvement culture which is outcome focused.

For manning best practice in the Australian mining industry, the result derived from performance evaluation and benchmarking studies can provide insight into the key drivers of manning requirements on mines and enable determination of appropriate manning levels.

In recent years, the shortage of skilled and experienced labour has been acute in the Australian mining industry; spread across all organizational levels including trades based roles, engineering and management positions. This has resulted in equipment being underutilized and some maintenance departments unable to fill all positions.

In the Australian context, labour represents a substantial component of most mine’s operating costs. Total direct labour costs can amount to 18% to 46% of total operating costs for underground mines (Figure 1) while total direct labour costs for open pit mines can range from 12 to 26% of total operating costs (Figure 2). There is no apparent clustering to indicate Australian gold mines are different from base metal mines.

Beyond direct salaries, on-costs can also be substantial and include state and federal labour related taxes, superannuation, worker’s compensation and entitlements. In addition, many Australian mines are located in remote areas away from the larger cities or regional centres, which force these mines to be operated on a fly-in/fly-out basis with commuting and remote allowances further increasing the resulting operational expenditure.

The impact of recent tightening of the credit market and weakness in mining commodity prices suggest that the labour shortages seen in recent years may, at least in part, decline. It is also anticipated that upward pressure on salaries and spiralling on-costs may have stalled. This creates a climate whereby the analysis of appropriate manning levels and industry best practice in this regard becomes even more crucial.

The Benchmarking Model

Over the past decade AMC Consultants Pty Ltd (AMC) has conducted over 60 detailed benchmarking studies at Australian and international open pit and underground, metalliferous mines. A number of longitudinal benchmarking studies, where annual or biannual performance is assessed over a number of years, have also been undertaken. AMC have developed detailed databases cataloguing mining practices, manning levels, technologies, costs and productivities.

The data gained through conducting these studies have enabled identification of the key drivers of best practices, hence the development of a benchmarking model, which is
a comprehensive and practical mine performance evaluation and reporting structure.

The Benchmarking Process
The initial stage of Benchmarking is information gathering. Information collected as part of the AMC process includes detailed cost data, equipment productivity data and manning levels.

The benchmarking team conduct a site visit to gain a thorough understanding of the activities involved and the operational issues specific to the mine. The knowledge of the people working on the mine site is as important as the data itself in conducting meaningful analysis. During the site visit the team liaise directly with key members of the operation’s workforce, collect primary data and observe all of the activities which are to be analysed and which may affect the benchmarking study.

For the benchmarking process to produce meaningful results, the data used must be accurate and consistent across the operations in the AMC database. To ensure this comparability of data, information is collected using standard templates, which contain clear definitions of the data required.

Cost and physical data are collected at the lowest possible level and allocated to the physical asset or individual activity such as a truck, or to the survey department, or perhaps, costs associated with an individual drill rig. Operational manning data are collected in the context of the organizational structure and labour roles. Through the processing of data in this way, costs, productivities and manning are able to be linked for meaningful comparison.

Processing of manning data
AMC have used standard manning templates based on typical organizational structures found at operating mines. Standard classifications are used for the collection and processing of data to allow meaningful comparison across a range of operational scales. These are shown for mining personnel at underground mines, mining personnel at open pit mines and for processing and general and administration personnel, in Figures 3, 4 and 5, respectively.

Manning productivities are compared on a tonnes per man day basis as tonnes per man shift can be distorted by different lengths of shift. One man day is considered equal to 24 hours. Also, maintenance personnel are allocated on an equipment/activity basis to ensure the total manning associated with individual operational activities are captured and reflected. Manning numbers are allocated in this way to ensure results are representative of underlying performance and comparable to other operations.

The Database
AMC’s benchmarking databases for underground and open pit present production, cost and performance results from 37 underground and 15 open pit benchmark studies in Australia. The data were collected as part of AMC’s
Figure 3. Underground manning classifications

Figure 4. Open pit mining manning classifications
ongoing benchmarking studies conducted since 1999. Underground operations range in size from 150 ktpa to 8.9 Mtpa of ore, and a full range of mining methods are represented. This paper focuses on mines with a mining rate of <3.5Mtpa. The underground database includes predominantly gold and base metal mining operations. Open pit operations range in size from 780 ktpa to 25.4 Mtpa of ore. The total material movement ranges from 7 Mtpa to 112 Mtpa. The open pit database includes gold, base metals and iron ore mining operations.

For the analysis of appropriate manning levels, an extract from the underground and open pit benchmarking database has been taken. The extracted data has been reviewed to confirm the reliability of the sub-set and in rare cases outliers have been removed. Outliers include missing data, zero figures and data that were not sufficiently detailed to support the analysis.

Where sufficient data have been available, trend analysis has been conducted. Plots are presented of the trends and control lines based on the standard error of the estimate, a measure of the variability around the fitted line of the regression. In all cases, trend analysis has been conducted using all the commodity types in the data-set, with base metal and gold operations plotted as different colours and symbols.

**Benchmarking results**

**Underground mining**

The underground manning data are processed into three broad classifications: mining, processing and general and administration. The proportion in each of these classifications is shown in Table I and in Figure 6. The proportion of mining personnel (including supervision and control, operations and maintenance personnel) is 60%, with a range (+/- 1 standard deviation) from 50 to 70%.

The relationship between ore tonnes mined and total mining personnel is shown in Figure 7. This data suggests that a minimum number of 60 persons is required for even the smallest underground operations.

Mining personnel can be further divided into two broad classifications: supervision and control and operations and maintenance (Figure 3). The proportion of each is shown in Figure 8 and it indicates operations and maintenance personnel constitute 39% to 79% of the total mining workforce. The remainder of the mining personnel are in supervision and control roles.

**Figure 9** examines the relationship between annual...
development metres and total mining manning numbers. The trend line indicates that a minimum of 50 persons are required, with an additional 30 mining personnel on average for each additional 2,000 metres developed. Gold mines are clustered in the lower 50th percentile, indicating better productivity than the base metal mines.

This relationship is confirmed using the productivity measure ‘metres per man day of lateral development’. This metric is shown in Figure 10 compared to the total number of mining personnel. The resultant trend line indicates better productivities with fewer people. Results for the gold mines are between 0.15 and 0.30 metres developed per man day, with base metal mines generally in the range 0.05 to 0.20. Factors such as ground control, drive dimensions and equipment used would effect the relationship between the meters developed and the number of people required. The lower quartile range is defined as >0.22 m/man day.

Another commonly used measure of underground mining productivity is the ore production per unit of worked time, typically measured as tonnes per man shift or tonnes per man day. In Figure 11, this measure has been compared against the total mining personnel levels. Little to no correlation in these two variables suggests that whereas mines may have larger numbers of mining personnel, they are not necessarily more productive. Other factors may also drive productivity beyond overall levels of manning, such as mining method, degree of automation, geology or ground controls.

The lower quartile range for all mines is defined as >70 t/man day, while for gold mines this reduces to >55 t/man day.

Finally, the relationship between underground mining method, ore production and mining personnel is plotted in Figure 12. Mining methods have been segmented into stoping and benching methods, caving methods and narrow vein mining methods (e.g. cut-and-fill). As expected, due to the small tonnage involved in narrow vein mining, these operations cluster at the lower limits of the production range. Alternatively, caving methods, which involve mining greater volumes, cluster at the higher end. For the operations in the database, there appears to be a clearly defined lower boundary in which no mines operate, suggesting that a minimum manning level exists irrespective of the size of the operation.

Open pit mining
The open pit manning data are processed into three broad classifications: mining, processing and general and administration. The proportion in each of these classifications is shown in Table II and in Figure 13. The proportion of mining personnel (including supervision and control, operations and maintenance personnel) is 60%, with a range (+/- 1 standard deviation) from 50 to 70%, the same as the underground data-set.

The relationship between ore tonnes mined and mining supervision and control personnel is shown in Figure 14. The trend line developed for this data suggests that a minimum number of 20 persons are required for even the smallest open pit operation.

The relationship between total material mined and mining operations and maintenance personnel is shown in Figure 15. The trend line for this data suggests that as the total material mined increases, mines continue to require more and more staff. In larger operations, better economies of scale are expected, resulting in an anticipated increase in productivity per unit personnel. The results based on the current dataset of 15 studies, suggest that larger mines are not necessarily more efficient in the use of operational and maintenance personnel. Gold mines in the database have lower production rates than the base metal mines and exhibit poorer correlation.

The proportion of supervision and control and operations and maintenance personnel for the benchmarking data-set is shown in Figure 16, indicating that operations and maintenance personnel range from 38% to 90% of the total mining workforce. The remainder of the mining workforce are in supervision and control roles. The lower quartile in this case is smaller gold mines, indicating the fixed nature of the supervision and control labour overhead. Discounting the lower quartile, the proportion of supervision and control is between 10 and 25% of the total mining workforce.

Figure 17 shows the relationship between ore tonnes per man day and the total number of mining supervision and control personnel. The proportion of mining personnel (including supervision and control, operations and maintenance personnel) is shown in Figure 13. The proportion of mining personnel (including supervision and control, operations and maintenance personnel) is 60%, with a range (+/- 1 standard deviation) from 50 to 70%, the same as the underground data-set.

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control personnel. It is generally anticipated that most mines produce 1,000 to 2,000 tonnes per man day with the best performing mines producing 3,000 or higher tonnes per day. The trend line of these results, informed by a current data-set of 15 studies, demonstrates poor correlation between ore tonnes per man day and the total number of mining supervision and control personnel. This suggests that the ore tonnes per man day may not have any significant relationship to the number of supervision and control personnel required in an operation.

Finally, Figure 18 shows the relationship between material mined and the total number of mining operations and maintenance personnel. The trend line shows a correlation between these variables, indicating that the better performing mines produce more than 3,500 tonnes per man day. The observed productivity drops may be attributable to high tonnage operations such as large open pits which are deep, have long haul distances due to large, widely spaced waste stockpiles and slower haul rates due to long ramp climbs. All of these factors effect personnel numbers. This metric reinforces the observations in Figure 15, highlighting the invariant nature of productivity for the gold mines in the database.

Ore processing
For the analysis of processing manning the underground and open pit operations were initially combined, based on the assumption that processing of ore is mineral specific and not related to mining method. Process plant supervision and control plus maintenance personnel have been included in these figures. Results have been coded by commodity and are shown in Figure 19. There is no clear trend line for these data; however, when underground mines were analysed separately (Figure 20), a trend for the overall dataset is apparent. The number of personnel for gold processing appears to be independent of the quantity of ore processed up to 2.0 Mtpa, indicating that the numbers of processing personnel are likely to be linked to other factors such as the processing technology, complexity of the ore, plant design and plant control philosophy.
General and administration

For the analysis of general and administration (G&A) manning numbers, the underground and open pit operations have also been combined and are shown in Figure 21. Results were also coded by commodity to determine if there are any trends in the data. Overall the results do not appear to display any trends based on commodity. Results may be distorted by some general and administration personnel being located off site or the use of contractors who have not been included in the organizational counts.

However, as with processing, the G&A manning levels for underground mines were analysed separately (Figure 22), revealing a trend for this data sub-set. The number of G&A personnel for gold mining operations appears to increase with the quantity of ore mined, generally informing the interquartile range (middle 50%).

Best practice

Best practice mines deliver their corporate goals by efficiently and effectively implementing their mine plan. Best practice mines have the following similarities:

- Sound mine planning and mine operational practices
- Appropriate equipment and manning levels
- Good information collection and reporting
- A continuous improvement culture which is outcome focused.

In the context of AMC’s benchmarking manning results, what assistance can these results provide in determining appropriate manning levels?

The benchmarking database demonstrates that for underground mining, a minimum number of approximately 60 personnel are required. Operations and maintenance personnel constitute from 39% to 79% of the total mining workforce, with the remainder in supervision and control. The metres of lateral development mined per man day demonstrates a correlation to numbers of mining personnel, with approximately 30 extra mining personnel needed for each additional 2 000 metres developed, but may also be influenced by other factors. Best practice for lateral development, defined by the lower quartile range is defined as >0.22 m/man day. As an overall measure of best practice for mine productivity, the lower quartile range for all mines is defined as >70 t/man day, while for gold mines this drops to >55 t/man day.

In terms of mining method used, a minimum manning level exists irrespective of the size of the operation and greater productivity is observed, with more tonnes mined per unit personnel. However, mines that have larger numbers of mining personnel do not necessarily produce more ore.

The benchmarking database demonstrates that for open pit mining, a minimum number of approximately 20 supervision and control personnel are required. Operations and maintenance personnel range from 38% to 90% of the total mining workforce; however as the size of the operation increases, the proportion is generally in the range 75 to 90%.

As the total material mined increases, mines are not necessarily being more efficient in their use of personnel and volume increases do not necessarily result in an increase in the number of supervision and control personnel required. The data suggest that the better operations produce more than 3 000 tonnes per man day.

The proportion of mining personnel (including supervision and control, operations and maintenance personnel) for all mining methods is 60%, with a range (+/-1 standard deviation) from 50 to 70%.

The benchmarking database demonstrates that for processing, a trend of increasing manning levels with the increasing ore processed is observable for underground mines. This same trend is not observed in combined open pit and underground data-sets. In terms of general and administration manning numbers, similar conclusion can be drawn.

The benchmarking results provide guidance by indicating a range of manning numbers and trends, which are likely to be appropriate for the scale and type of a range of mining operations. However, as a number of other factors also have influence, so the Benchmarking results should be used with caution when determining appropriate manning levels.

Appropriate manning levels are not just a ‘numbers game’ where having the lowest manning levels reflects best practice. Individuals get work done within the context of the organisation and insufficient levels of manning can result in not all the work that needs to be done, getting done. For a mining operation this can mean inadequate maintenance being performed, lack of supervisory personnel to manage a key contractor, or a shortage of planners to update short, medium, or long-term plans. Clearly these are undesirable outcomes with potentially significant detrimental impacts on factors such as safety or efficiency.
Appropriate manning levels are strongly related to the way in which work is organized. Factors such as role clarity, organizational structure, workplace processes, use of information technology such as mine automation, and work complexity all influence manning levels.

Furthermore, the skill levels of the individuals within particular work roles are important in determining manning levels. An under-skilled workforce will require more support including mentoring and workplace training. This is likely to increase overall manning numbers, but produce better outcomes.

When the manning results are reviewed with productivity and cost data they are helpful in identifying areas for potential business improvement. When benchmarking is conducted on a periodic basis, the productivity data can be used as a formative tool for continuous improvement. Analysis of manning levels through benchmarking is a method that enables the efficiency of labour to be systematically compared.

For manning best practice in the Australian mining industry, the result derived from performance evaluation and benchmarking studies can provide insight into the key drivers of manning requirements. This can lead to the development of a best practice approach incorporating sound mine planning and mine operational practices, appropriate equipment and manning levels, and an outcome focused, continuous improvement culture.

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References

AMC Consultants underground and open pit mines benchmarking database.

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AMC Consultants, Principal Mining Consultant - strategic planning and financial analysis aimed at optimizing the value of mining operations. 24 years experience in the mining industry—mine operations, mine planning and design, economic and financial evaluation. Specialist expertise in block caving, particularly management of block cave draw control.