Precise positioning in the mining sector

An estimate of the economic and social benefits of the use of augmented GNSS in the mining sector

Prepared for the Department of Industry, Innovation, Climate Change, Research and Tertiary Education

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Executive Summary

The mining sector has been an early adopter of geospatial technologies in exploration, development and operation of petroleum and mining projects. Maintaining international competitiveness is a top priority for companies in this sector. At the same time, the industry must also maintain high safety and environmental standards.

Augmented GNSS is an increasingly important enabling technology for the use of geospatial systems in the industry. For most applications, the sector requires accuracies of around the cm to 10 cm level. Higher accuracies are required for mine site surveying, autonomous operation of mine machinery and machine guidance. Lower accuracies are adequate for activities such as environmental surveys, monitoring and material tracking.

The requirement for improved positioning accuracy as well as reliability and integrity is increasing as operation control and machine guidance become automated. Across the mining industry augmented GNSS is used for:

- exploration
- marine operations
- mine site surveying
- autonomous mining and operations control
- remote control of vehicles and machines, including haul tracks and drilling equipment
- vehicle tracking and dispatch
- loading systems
- material tracking along the supply chain
- preserving areas of cultural heritage and high environmental value.

Augmented GNSS is also an important enabling technology for automated mining which is increasingly likely to become the way of the future for mining operations.

Depending on the application and the level of automation of a mine site, productivity gains can include labour force reduction from between 5 per cent\(^1\) and 50 per cent\(^2\), with overall productivity gains ranging between 1 per cent\(^3\) and 15 per cent\(^4\).

Economic modelling undertaken by ACIL Allen estimates that output from the mining sector was between $683 million and $1,085 million higher in 2012.

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\(^{1}\) Personal Communications – BHP Billiton  
\(^{2}\) McNab and Garcia-Vasquez 2011  
\(^{3}\) Personal Communications – BHP Billiton
than it would otherwise have been as a result of the use of applications based on augmented GNSS. This could rise to between $2,439 million and $3136 million by 2020 with further use of automated mining and related applications.

With future developments in mine surveying, autonomous mining, machine guidance and further advances in augmentation of GNSS, the future gains are achievable. However, ubiquitous positioning through strategies such as further development of CORS networks and development of GNSS consistent augmentation in deep pits will be required if these gains are to be realised.

Additional benefits that are derived from the use of augmented GNSS include improved health and safety outcomes in mining operations, with positioning becoming particularly important to mitigating and managing risk across operations

Augmented GNSS is increasingly being used to support environmental management at mine sites, reducing waste, more effective material management and reducing fuel use. The spatial relationship between data collected on-site, including contaminate, wastage and processing bi-product is continually being collated and used to minimise environmental impacts.

**Key Findings**

- The mining sector has been an early adopter of precise positioning technologies with productivity benefits realised through operational efficiency improvements, including the reduction of operating costs and waste.
- The main benefits from the use of augmented GNSS have been significant operational efficiencies in reduced labour costs, reduced fuel costs and increased yield. These have delivered significant economic benefits for the industry and the economy.
- Augmented GNSS has reduced labour costs for mine site surveying by between 30 and 40 per cent. Automated mining is reported to have delivered overall productivity gains of up to 15 per cent.
- The cost of down time in the operation of seismic vessels in the offshore petroleum sector is has been reduced by around 10 per cent as a result of the use of augmented GNSS.
- Augmented GNSS also contributes to improved safety and environmental management at mine sites. It is also used at the planning stage for activities such as mapping of areas of cultural heritage sites.
- Augmented GNSS is required for automated mining operations and machine guidance. Such techniques are seen by leaders in the industry as the foundations for the mine of the future.
- Future benefits will depend on further expansion in the availability of precise positioning technologies of which augmented GNSS is at the centre. Greater compatibility between systems will assist further use and application of augmented GNSS.
1 Introduction

ACIL Allen Consulting, in partnership with SKM and Lester Franks Surveyors and Planners, has been commissioned by the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education to assess the value of augmented positioning services in Australia.

The purpose of this report is to provide an understanding of the economic and social benefits of precise positioning information within the mining sector. This information is to allow better informed decision-making and assist in identifying areas for growth and investment from both the private sector and government. It will also provide context to the National Positioning Infrastructure Plan being developed by Geoscience Australia.

2 The mining sector and precise positioning

The mining sector is one of Australia’s most important sectors of the Australian economy. Value added in the sector was around $140 billion or about 9.4 per cent of GDP in 2012. The mining industry itself employed around 271,000 people in August 2012 (ABS, 2012).

Mining broadly relates to the exploration for and extraction of minerals occurring naturally as solids, such as coal and ores, liquids such as crude petroleum, or gases such as natural gas. Included are activities carried out at or near mine sites as an integral part of mining operations, such as dressing or beneficiation of ores or other minerals.

Environmental and safety standards are important considerations in the industry. Environmentally sustainable and safe operations are expected by the community and are accordingly high priorities for the industry.

2.1 Use of precise positioning in the mining industry

The mining sector has traditionally been an early adopter of new technologies, with a process of incremental innovation over many decades. The level of innovation has accelerated over the past 15 years with the emergence of new technologies that support greater control over mining processes and, more recently, the introduction of further automation in mining.

At the core of these technologies are geospatial and mapping systems that enable precise location of mine facilities and machines to be recorded, monitored and guided. To achieve this level of control it is essential that position is known to between 1 cm and 10 cm. This accuracy can be delivered
with augmented GNSS systems and their application through commercial and other services has increased over the past 15 years\(^4\).

For this report the consultants undertook a review of existing literature, researched seven case studies and drew on consultations with industry leaders to explore the applications of precise positioning and estimate the net benefits of its use in the mining sector.

An analysis of available information and case studies provided supporting evidence of cost reductions in labour and materials. This evidence was used with estimates of levels of adoption to calculate industry wide productivity and improvements as at 2012 and projected for 2020.

### 2.2 Exploration and mine site surveying

Exploration and mine site surveying are dependent on precise positioning to facilitate multiple facets of a project lifecycle, ranging from the exploration of onshore and offshore mineral and hydrocarbon deposits, to the establishment and management of mining and petroleum production facilities. Applications of precise GNSS to these areas are discussed in Sections A.3 and A.4 of Appendix A.

#### 2.2.1 Exploration

For exploration, precise positioning is typically required at the decimetre level utilising DGPS corrections relayed by satellite communications as compared to precise positioning which is associated with RTK\(^5\) systems delivered from localised base stations.

Whilst centimetre level real time positioning is not widely required, there is a heavy reliance on the integrity and reliability of positioning, particularly for geophysical surveys and other exploration activities.

Whilst DGPS\(^6\) is the primary service utilised under exploration activities, there is a small reliance on RTK systems for important shore crossing / transition zones for pipeline connectivity. The reliance of independently operated RTK base stations for such activities is particularly important given the increased requirement for accuracies for construction and management of pipelines.

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4 See the Overview Report for information on GNSS and augmented GNSS.
5 Real time kinematics involved correction signals from one or more base stations generally delivered by radio signals, mobile phone or the internet to local receivers. The CORS network in some states is one example of an RTK system.
6 Differential GPS is a form of augmented GNSS. The correction signals can be transmitted to the GNSS receiver by satellite or radio signal. Commercial DGPS services that are utilised by the mining industry.
Benefits

Benefits derived from exploration include:

- reduced timeframes and improved efficiency for data acquisition
- full integration of GNSS with navigation and positioning systems
- improvement in reliability and uncertainty of positional accuracy (improving efficiency of exploration process)
- reduction in positional uncertainty for delivered data

One company estimated that around 10 per cent of offshore exploration expenditure can be lost due to downtime which is in part attributable to poor navigation data and inefficiencies in steering survey vessels. More precise GNSS signals contribute to reducing lost down time. (see Appendix A).

2.2.2 Mine site surveying

Precise positioning is central to most mine site surveying processes. This includes pipeline location, pit layout, underground and construction operations over the entire course of the project lifecycle. Adoption levels of precise positioning for site surveying would be at near 100%, with surveying typically being at the forefront of precise GNSS development and methodology to maximise benefits.

Details of applications of augmented GNSS to mine site surveying are provided at section A.4 at Appendix A. The areas where adoption has occurred include:

- coordination of survey control
- survey of all composite services mapping
- topographical and feature survey for design
- progressive ground model surveys during construction to assist in the volumetric surveys for contractor payment
- set out of design
- set out of boundaries
- survey of cleared areas
- as constructed surveys.

Benefits

Benefits identified from case studies and research include:

- instant connection to site control
- efficiency in site survey updates (construction, utilities and services)
- reduced on-site surveyors (labour) required for data capture as site is developed
- construction contractors can connect directly to localised control and upload digital plans as they are developed
The mining sector and precise positioning

- interoperability between survey and construction
- real-time material tracking and stockpile management
- reduced operating costs.

The productivity benefit is mainly derived from reduced labour costs and accounts for around 30 to 40 per cent.

A major benefit is the reduction in the number of surveyors to one for the majority of tasks and the increased efficiency of GNSS technology in supplying real-time position information at cm level is the key realisation of benefit.

Reductions in labour costs are important to the Australian petroleum and mining industry due to the remote operations and the relatively high cost of labour for these areas.

2.3 Automated mining

At present given the scarcity and remoteness of mineral resources, the lack of skilled labour, challenging locations and harsh environments, the focus in mining innovation is on the development of remotely operated and autonomous equipment and related systems. A key component of this development is the availability of real-time precise positioning, typically provided by GNSS augmented by other sensors.

Whilst the development of automated mining has been underway for a number of years, particularly in the open pit mining area, there is a growing recognition in the industry of the benefits of the technology. Full adoption and commercial use by all miners across multiple sites is likely to be achieved in the medium term.

Mine automation includes automation of operations as well as haulage trucks. These technologies are supported by augmented GNSS.

Examples of the applications of automated mining can be found in the operations of large miners such as BHP, Rio Tinto and Fortescue Metals Group. All have invested significantly in automation for certain mining applications. A case study of an application involving autonomous haul trucks is provided in the case study in section A.1 of Appendix A.

Rio Tinto, as part of its Mine of the Future program, has become owner of the world’s largest fleet of driverless trucks which will be used in their Pilbara

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7 Ilia Milan SKM – Personnel Communication
8 Autonomous and remote operation technologies in Australian Mining November 2011.
9 International Mining August 2011
10 http://www.riotinto.com/media/5157_21165.asp
iron ore mines in Western Australia with the aim of reducing costs, increasing efficiency and improving health, safety and environmental performance.

Box 1  

**Autonomous haulage**

Autonomous haulage is an important component in our Mine of the Future™ program. These 150 new trucks will work with our pioneering Operations Centre that integrates and manages the logistics of 14 mines, three ports and two railways. These technologies are revolutionising the way large-scale mining is done, creating attractive hi-tech jobs, and helping us to improve safety and environmental performance and reduce carbon emissions.” Greg Lilleyman - Rio Tinto Iron Ore President Pilbara Operations

Source: Interview

Precise positioning at the decimetre level is critical to autonomous operations, to support needs such as object detection and collision avoidance. Augmented GNSS is required for these applications. Stand-alone GNSS cannot be reliably used as the primary control due to issues surrounding availability and integrity. There is a much broader adoption of precise positioning, over a range of other applications with its use now becoming ubiquitous across the mining sector.

**Benefits**

The benefits of automation include:

- increase in operational efficiency (including fuel efficiencies) through better management and monitoring of fleet vehicles and plant
- improvement in safety (less reliance on human controlled heavy machinery)
- pre-defined and pre-loaded schedules.

Initial trials of semi-automated fleets at the Peak Downes (BHP BMA) coal mine have produced encouraging results in relation to improved fleet monitoring, efficiency and optimisation (see case study at Section A.1 in Appendix A). Whilst at this stage only semi-automation is being conducted (that is trucks still must have drivers), precision GNSS data feeds into Intelligent Vehicle Systems (IVS) to produce data that is monitored via a central control platform and used to enhance efficiency of the 100 plus fleet.

Depending on the application and the full automation of a mine site, productivity gains can include labour force reduction from between 5 per cent\(^{11}\) and 50 per cent\(^{12}\) (Yeates 2012 & McNab and Garcia-Vasquez 2011), with overall productivity gains ranging between 1 per cent and 15 per cent\(^{13}\).

**Adoption Factors**

\(^{11}\) Personal Communications – BHP Billiton  
\(^{12}\) McNab and Garcia-Vasquez 2011  
\(^{13}\) Personal Communications – BHP Billiton
Currently autonomous haul trucks are being utilised by Rio-Tinto and in the test phases of a number of BHP-Billiton operations. Further take-up by smaller operators will most likely depend on the successful implementation of these larger scale projects.

Integral to the adoption of precise positioning technologies is the reliability of both the positioning information and its ability to be integrated within systems that facilitate these applications. These systems are increasingly being automated and incorporate augmented GNSS.

A potential limiting factor within the mining sector is the incompatibility of precise GNSS between different operations. For example where either adjacent mining operations owned by the same company have incompatible precise positioning systems\textsuperscript{14} or are operating disparate proprietary commercial positioning systems. Incompatibility is an issue that is inherent within the mining industry and arises due to the lack of existing support infrastructure and the requirement to individually tailor positioning needs to each specific site operation.

Given this lack of supporting infrastructure such as the existence of a national or regional CORS network, site specific equipment is installed and maintained independent from larger networks. As such, there is an increasing reliability on often a single base station and its model/make to support positioning requirements.

Another factor is the availability and degradation of GNSS signal in deep pit operations. The increasing depths at which some pits are now operating limits the availability of the GNSS signal. GNSS is also not applicable to underground operations.

There are alternative solutions to these problems. Newmont have recently augmented their deep pit operations at Boddington with GNSS transmitters (repeaters) based on GNSS and terrestrial augmentation to strengthen the coverage of GNSS and increase availability of high precision positions for its underground mine at Boddington in Western Australia. This development by Leica based on Locata technology can extend GNSS positioning into underground mining. More information on this system is provided in section A.5 of Appendix A.

More generally equipment and research and development costs, whilst impeding smaller operations, do not seem to be a limiting factor given the magnitude of operations that precise positioning potentially supports and the perceived benefits (both efficiency and safety) amongst large operations conducted by mining companies such as Rio Tinto, BHP and Newmont.

\textsuperscript{14} Economic benefits of high resolution positioning services, Allen Report 2008
However, assurances that the systems are reliable, particularly for real-time support, are at the forefront of investigations and trials, especially given the increasing emphasis on safety performance records across industry.

Uptake of autonomous and remote operating technology will be influenced by the current economic climate and the need for companies to gain competitive advantage through investment as well as the compatibility of technologies across industry.

There is a general estimation of between 30-40% reduction in the mining workforce (50% within operational roles) at those operations which adopt large-scale automation, with truck driving the most likely function to be carried out autonomously at a large scale (McNab and Garcia-Vasquez 2011).

### 2.4 Machine guidance

Application of machine guidance control systems are discussed in Section A.2 of Appendix A. Machine guidance includes automated drilling and excavator control which is used in many major mining operations. It allows the operator to perform a more accurate drilling and excavation, saving on passes made, time and machine wear and tear.

This is applicable to not only excavation and drilling, but grading, loading, stockpile management and earthworks as well. The operator still guides the machine and is in full command. However guidance is provided from the input of real time positioning.

Machine control is supported by augmented GNSS positioning referenced RTK corrections based off a pre-defined base station established on local site datum for effective cm level positioning. The latest digital site plans (defining topography) are then loaded into control system to establish locations and depths of areas of interest (i.e. ore bodies) to target specific extraction operations.

The main benefits identified include:

- yield gains
- efficiency (continuous operation without shift changes)
- controls the dispatching of machines based on the production plan and availability of load points and dump points
- fewer waste products given more targeted digging
- evaluation software to analyse productivity of digging operations
- reduced number of grade checkers
- reduced Lost Time Injuries due to machine/human interaction
- reduction in double handling
- working life of machinery is increased
- machine operated remotely
• reduction in operational costs
• production and condition monitoring reports easily generated from control systems tracking the precise excavation / drilling procedures.

**Productivity Estimates**

In 2008 it was estimated that selective mining and machine guidance technology was being used by about 15% of open cut mines in Australia (The Allen Consulting Group, 2008). Current industry consultations suggest that the adoption rate has increased considerably, with some parts of the sector now experiencing upwards of 60% adoption. The ability to target ore bodies and minimise wastage is producing perceived benefits of up to 10% of total productivity.

Given the emphasis on machine guidance, mining operations can withstand difficult conditions (i.e. poor visibility) and increase production in scenario’s where previously operations would be heavily impacted. This has a direct impact on the productivity of the mining operation by minimising down-time associated with poor conditions. Within Australian conditions this is particularly relevant given the extremities of both storms and heat in many mining regions.

### 2.5 Social, cultural and environmental applications

Additional benefits that are derived from precise GNSS applications in the mining sector include increased health and safety in mining operations, more effective surveying of areas of cultural and environmental values and more precise monitoring of environmental impacts and environmental baselines. The latter is critical to sustaining a licence to operate. Examples are discussed in Appendix C.

Further applications emerging from both automation and advanced positioning, relate to collision avoidance systems which remove the risk of collisions and accidents at the mine site.

Surveying of cultural heritage sites requires augmented GNSS. The case study cited in Appendix C shows that using precise GNSS the Snowy Mountains Engineering Corporation was able to identify heritage sites in the route of coal seam gas pipelines. This work requires at least 1 metre accuracy as some artefacts are relatively localised.

Accurate sub-meter data can be utilised as the basis of plans for mitigating the effects on tourism and rainfall runoff in the areas within and adjacent to heritage sites. The implementation of infrastructure such as roads, pipelines or railways may have an adverse effect on adjacent cultural heritage sites. By

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15 Personal Communications Gavin Yeates – BHP Billiton
utilising high accuracy Digital Elevation Models (DEM), simulations such as flow direction models, weathering profiles and human influence can be modelled prior to infrastructure construction approvals.

Mapping of environmental changes, natural or anthropogenic, in and around cultural heritage sites, assists in the assessment and planning of protection and preservation methods. High accuracy measuring systems are required to provide meaningful data, yet these are not available due to the majority of sites remote locality and the cost of implementation. Sites already known to be at risk from a variety of negative factors may have their life extended through effective mapping, planning and the introduction of procedures to mitigate current threats.

### 3 Emerging Technologies

Given the mining industries commitment to implementing new technologies on the basis of improving both operational efficiency and safety, it has continued to adopt precise positioning applications at a rapid rate. A large component of future development is likely to not only involve new applications, but also refine the reliability and integrity of existing uses (such as the reliability of autonomous mining).

Underground navigation is an area of mining that is currently not supported by GNSS precise positioning applications. The reasons for this simply being the restriction of satellite signals to underground facilities. Currently, methods of radar imaging are used to support underground operations. However future directions may see the implementation of repeater signals that can re-distributed the appropriate satellite corrections and process system position on site specific data. This will aid in the augmentation of radar imaging methods that are not as reliable as GNSS positioning applications.

As discussed earlier in this report, Newmont have augmented their deep pit operations at Boddington with GNSS transmitters (repeaters) to strengthen the coverage of GNSS and increase availability of high precision positions. The improvement of augmented positioning systems has increased reliability to levels of dependency around 90%. Through greater availability and dependency, significant productivity gains are being realised.

Rio-Tinto has already publicly launched an ambitious ‘Mine of the Future’ program, which highlights the adoption autonomous and remotely operated equipment.

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**Box 2**  
**A changing face of mining**

“Rio Tinto is changing the face of mining... We’re aiming to be the global leaders in fully integrated, automated operations. It will allow for more efficient operations and directly confront the escalating costs associated with basing employees at remote sites, giving us a competitive advantage as an employer along the way.”

Source: Tom Albanese, Chief Executive, Rio Tinto [Rio Tinto, 2008]
Precise positioning is an obvious key component within these strategic directions. Future directions will be therefore dictated by reliability, adaptability, and accuracy of the supporting infrastructure that facilitates the transferral of precise positioning to implemented systems.

4 Economic impacts

Economic impacts in the mining sector can be driven by several factors. Increases in productivity deliver direct benefits to operations from lower costs, higher production and sales which lead to overall increases in net revenues. Dynamic benefits can also arise from innovation particularly in mine site operations and materials handling.

Productivity as reported by the Australian Bureau of Statistics has been decreasing in the mining sector over the last ten years (ABS, 2012). This is thought to be attributable to significant investment in production capability that is yet to feed through into volumes exacerbated by resource depletion (Zhao, November 2012) (Top, 2008). This appears to have offset other improvements in efficiency that have been observed in our case studies and research.

With falling commodity prices, continued improvement in productivity is a high priority for the mining sector as the case studies demonstrated.

We have estimated productivity improvements with evidence gathered from the cast studies, our estimates of current and future levels of adoption, published research and reports and from interviews with industry participants.

4.1 Direct productivity impacts

Estimates of accumulated productivity impacts and cost savings for the utilities sector for 2012 and additional impacts likely to accrue by 2020 are summarised in Table 1 and Table 2 respectively.

The tables are based on case studies undertaken by SKM. It provides the base assumptions in each area and reports the productivity impacts that have been used for the economic modelling.
### Table 1  Direct impacts – mining and petroleum 2012

<table>
<thead>
<tr>
<th>Enterprise</th>
<th>Assumptions</th>
<th>Direct impact (Low)</th>
<th>Direct impact (High)</th>
</tr>
</thead>
</table>
| Oil and Gas                 | Exploration Surveying  
|                             | • 1.9 % increase in efficiency of identified tasks attributable to more efficient coverage steerable of survey area. Benefit also from reduced downtime.  
|                             | • 2% adoption low case, 3% adoption high case                                                                                                                                                               | 0.029%              | 0.048%               |
| Construction (Pipeline)     | Facilitation of precise positioning for construction applications and also asset management in transitional zones (Under-Water pipelines and their connectivity to Plant) - 0.25% productivity, adoption 1% low, 2% high | 0.003%              | 0.005%               |
| Site Maintenance / Construction | Site Surveying  
|                             | • Volumetric calculations  
|                             | • design and construction  
|                             | • full adoption rates  
|                             | • 0.12% productivity, adoption 60% low, 65% high                                                                                                                                                            | 0.070%              | 0.098%               |
| Selective Drilling          | Selective drilling used to automated drilling procedure and target ore bodies  
|                             | • increased operation efficiency 30%  
|                             | • reduction in Labour costs 20%  
|                             | • reduced Machine Wear and Fuel costs  
|                             | • Improved safety performance 0.32% productivity, adoption 1%-2.5%                                                                                                                                       | 0.003%              | 0.008%               |
| Autonomous Trucks           | Based on current projections from operations across BHP (Peak Downes) and Rio Tinto trials.  
|                             | • optimisation  
|                             | • efficiency  
|                             | • fleet management  
|                             | • 1.33% productivity , 15%-25% adoption                                                                                                                                                                   | 0.200%              | 0.267%               |
| Loading Systems / Yard Servicing |  
|                             | • improvement in operational efficiency  
|                             | • management of utilisation  
|                             | • optimisation of services  
|                             | • 0.1% productivity, 15%-20% adoption                                                                                                                                                                     | 0.015%              | 0.020%               |
| Automated mining            | • Reduction in overall operating costs – 3.3 per cent  
|                             | • Adoption 10% for low estimate, 15% for high estimate                                                                                                                                                   | 0.329%              | 0.493%               |

Note: Productivity and savings are accumulated from 1995. Productivity is expressed in terms of sector output.
Source: SKM, ACIL Allen, case studies, industry consultations and research.
Table 2 Projected Impacts – mining and petroleum by 2020

<table>
<thead>
<tr>
<th>Enterprise</th>
<th>Assumptions</th>
<th>Direct impact (Low)</th>
<th>Direct impact (High)</th>
</tr>
</thead>
</table>
| Oil and Gas                       | Exploration Surveying  
• 1.9% increase in efficiency of identified tasks attributable to more efficient coverage steerage of survey area. Benefit also attributed to reduced downtime as a result of poor positioning. Adoption 3%-4% | 0.048%              | 0.076%               |
| Construction (Pipeline)           | • facilitation of precise positioning for construction applications and also asset management in transitional zones (Under-Water pipelines and their connectivity to Plant) - 0.25% productivity, adoption 3% low, 4% high | 0.008%              | 0.010%               |
| Site Maintenance / Construction   | Site Surveying  
• volumetric calculations  
• design and construction  
• full adoption rates  
• 0.12% productivity, adoption 70% low, 75% high | 0.222%              | 0.238%               |
| Selective Drilling                | Selective drilling used to automated drilling procedure and target ore bodies  
• increased operation efficiency 30%  
• Reduction in Labour costs 20%  
• Reduced Machine Wear and Fuel costs  
• Improved safety performance 0.32% productivity, adoption 20%-25% | 0.083%              | 0.099%               |
| Autonomous Trucks                | Based on current projections from operations across BHP (Peak Downes) and Rio Tinto trials.  
• Optimisation  
• Efficiency  
• Fleet management  
1.33 productivity, 50%-70% adoption | 0.667%              | 0.933%               |
| Loading Systems / Yard Servicing  | • Improvement in operational efficiency  
• Management of utilisation  
• Optimisation of services  
• 0.1% productivity, 25% - 30% adoption | 0.025%              | 0.030%               |
| Automated mining                  | • Reduction in overall operating costs – 3.3 per cent  
• Adoption 25% for low estimate, 35% for high estimate | 0.824%              | 1.153%               |

Note: Productivity and savings are accumulated from 1995. Productivity is expressed in terms of labour and materials costs for the sector. Source: SKM, ACIL Allen, case studies, industry consultations and research.

These accumulated productivity impacts are translated into industry wide direct impacts and summarised in Table 3. These direct impacts reflect reduction in costs from productivity improvements identified in the above tables.

Table 3 Mining industry productivity improvement

<table>
<thead>
<tr>
<th>Low estimate</th>
<th>High estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity</td>
<td>Productivity</td>
</tr>
<tr>
<td>2012</td>
<td>0.603%</td>
</tr>
<tr>
<td>2020</td>
<td>1.863%</td>
</tr>
</tbody>
</table>

Note: Productivity impact is on costs.  
Data source: SKM and ACIL Allen analysis, based on case studies and research.
4.2 Impact on the mining sector

The productivity impacts summarised in Table 3 were used as inputs to ACIL Allen’s Computable General Equilibrium (CGE) model, Tasman Global\textsuperscript{16}, to estimate the impacts that productivity improvements from the use of augmented GNSS has had on the Australian economy in 2012 and the potential benefits that could arise by 2020\textsuperscript{17}.

The results from this modelling for output from the mining sector are shown in Table 4.

Table 4 Impacts on output

<table>
<thead>
<tr>
<th></th>
<th>Low case 2012</th>
<th>High case 2012</th>
<th>Low case 2020</th>
<th>High case 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in output $ million</td>
<td>682</td>
<td>1,084</td>
<td>2,437</td>
<td>3,134</td>
</tr>
<tr>
<td>Percentage of total output</td>
<td>0.4%</td>
<td>0.7%</td>
<td>1.1%</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

Note: Amounts are in $2012

Data source: ACIL Allen modelling

The table shows that output in the sector is estimated to have been between $682 million and $1,084 million higher in 2012 as a result of the use and application of augmented GNSS. This represents 0.4 per cent and 0.7 per cent of total output for the sector.

Output is projected to be between $2,437 million and $3,134 million higher by 2020. This represents 1.1 per cent and 1.4 per cent of total output for the sector.

The higher projected outcomes for 2020 are attributable to increased adoption of the identified technologies across the mining sector plus the adoption of fully automated mining in some mines. These increases are dependent on expansion of augmented GNSS services and the development of GNSS compatible services that will operate in deep pits and underground. As discussed earlier in the report, these will need to be compatible across services.

\textsuperscript{16} See overview report for a full description of the CGE modelling approach,

\textsuperscript{17} Note that the productivity shocks for other sectors discussed in this report were also entered into the model at the same time.
Appendix A  

Case studies

A.1  Autonomous Haul Trucks

Autonomous Haul Trucks stands as one of the main components of current and future automation objectives amongst larger mining operations. This application requires the installation of precise GNSS navigation equipment to remotely control vehicle movement and dumping against an updated pit database\(^{18}\).

![Autonomous Haul Truck](image)

**Figure 1  Autonomous Haul Truck**

Data source: Rio Tinto

Volvo (Volvo Construction Equipment) President and CEO, Excavators, Mike Rhoda says he is in favour of the move towards autonomous technology

"As the technologies develop and machine positioning systems mature, then it will become increasingly feasible to envision a machine that doesn’t require an operator to run: Rhoda says.

Source: Personal communication

Whilst GNSS is integrated amongst the controlling systems, it is typically not the primary source of positioning and is augmented by other sensors to ensure system reliability. Whilst GNSS reliability is improving rapidly, there is still limited confidence to support stand-alone GNSS applications or even the

\(^{18}\) Sources: Rio Tinto / BHP BMA (Peak Downes)
adoption of the technology as the primary controlling system, thus it is frequently augmented amongst other positioning techniques (such as radar) to ensure integrity, this is particularly relevant to deep pit operations.

On-Board computers attached to these positioning sensors including (high precision GNSS) are used to operate communications, guidance and avoidance systems (BAEconomics 2012). Navigation amongst open-pit operations is able to fully utilise the more effective high precision GNSS techniques, however underground operations typically take advantage of Radar imaging systems due to the inefficiencies of signal transmission underground.

Amongst the open pit operations, pre-defined GNSS courses are loaded into the system to help with the following applications:

- navigate haul roads and intersections
- move within the loading and dumping areas
- enter the tie-down area for refuelling; and
- interact with manned equipment such as excavators, graders, bulldozers and light vehicles.

**Benefits**

The benefits of automation include:

- increase in operational efficiency (including fuel efficiencies)
- improvement in safety (less reliance on human controlled heavy machinery)
- remote fleet management
- pre-defined and pre-loaded schedules
- reduction in operational costs
- monitors fleet condition.
  - Onboard machine measurements and alarm information is provided to the system operator and also logged to a database.
- monitors fleet production.
  - Tonnages are stored to a database along with loading and dumping point identification and cycle time information.

Currently Autonomous Haul trucks are being utilised by Rio-Tinto and in the test phases of a number BHP-Billiton operations. Further take-up by smaller operators will most likely hinge on the successful implementation of these larger scale projects.

Initial trials of semi-automated fleets at the Peak Downes (BHP BMA) coal mine have produced encouraging results in relation to improved fleet monitoring, efficiency and optimisation. Whilst at this stage only semi-automation is being conducted (that is trucks still must have drivers), GNSS data feeds into Intelligent Vehicle Systems (IVS) to produce data that is monitored via a central control platform and used to enhance efficiency of the 100+ fleet.
Uptake of autonomous and remote operate technology will be influenced by current economic climate and the willingness of companies to gain competitive advantages through investment as well as the compatibility of technologies across industry (McNab and Garcia-Vasquez 2012).

A.1.1 Productivity Estimation

There is a general estimation of between 30-40% reduction in the mining workforce (50% within operational roles) at those operations which adopt large-scale automation, with truck driving the most likely function to be carried out autonomously at a large scale (McNab and Garcia-Vasquez 2011).

At BHP’s Mouth Kieth nickel mine, a 75% reduction in overall workforce was estimated as a result of fully automating the haul truck fleet (Bellamy and Pravica 2010).

Whilst this technology is still being trialled and evaluated through a large number of operations, there is a realised benefit in improved fleet management. BHP BMA have expressed that use of positioning amongst operational trucks has improved scheduling, loading capacity, fuel efficiency and reduced machine wear. Estimates as to precise numbers are still being currently evaluated and detailed figures are not available at this stage.

A.1.2 Adoption Costs

Rio Tinto has invested heavily in the automation of not only Haul Trucks, but full mine automation with an ambitious ‘Mine of the Future’ program being outlaid for the upcoming decade and already in full trial mode since 2008 (at West Angelas open pit iron ore mine in the Pilbara).

Box 4 Mines of the future

“Mine of the Future™ will help us improve our sustainable development performance in several areas. The programme is designed to create next generation technologies for mining operations that result in greater efficiency, lower production costs, improved health, safety and environmental performance, and more attractive working conditions” (Rio Tinto 2012)

Source: Greg Lilleyman - Rio Tinto Iron Ore President Pilbara Operations

Central to the development and realisation of full mine automation is the adoption of high precision site specific GNSS technologies to support not only Autonomous haul trucking but other applications such as accurate selective mining. Fully functional test sites have been trialled successfully since 2008 and are now the basis of technological role out amongst several live operations.

In 2011 Rio Tinto publicly announced that autonomous fleets would double and be deployed at Rio’s Yandicoogina mine following the successful tests at West Angelas. The increase in driverless fleet is set to increase to 40% of total capacity at approximately 150 vehicles by 2015 (Rio Tinto 2012).
A.2 Machine guidance/automated drilling

Accurate selective mining precisely locates the relative positions of both excavator and bucket via GNSS technologies to precisely guide the excavation process to predefined locations and depths. This technology improves both efficiency and productivity of the excavation process.\(^\text{19}\)

In addition to selective mining, autonomous drilling can accurately pinpoint each drill location and use position to control precise levelling and true vertical drilling. GNSS guidance can be used to precisely position drills in accordance with the location of resources and drill depths can be accurately programmed.

Both techniques maximise ore recovery from the ore body and provides more predictable operational outcomes, improving forecasting. It also maximises productivity through more continuous (and safe) operation non-reliant on human operation.

A.2.1 Machine Guidance

The various machine control systems used amongst major mining operations allow the operator to perform a more accurate, targeted job, saving on passes made, time and machine wear and tear. This is applicable to not only excavation and drilling, but grading, loading, stockpile management and earthworks as well. The operator still guides the machine and is in full command; however guidance is provided from the input of real time positioning.

Machine control is augmented via GNSS positioning references RTK (Real Time Kinematic) corrections based off a pre-defined base station established on local site datum for effective cm level positioning. Latest digital site plans (defining topography) are then loaded into control system to establish locations and depths of areas of interest (i.e. Ore Bodies) to target specific extraction operations.

BHP Billiton Mitsubishi Alliance (BMA) own and operate seven mines within the coal-rich Bowen Basin, Queensland. BMA are currently realising automated drilling at one of their key operations, the Peak Downes site. This technology has only just been implemented (2012) and productivity assessment are still being evaluated. With initial trial period assessments being flagged for evaluation by the end of the year, it is hoped that the technology will be rolled out amongst 2 further mines (Daunia and Cattle Ridge) within the upcoming year.

Rio-Tinto as part of their investment in Autonomous systems has currently deployed 4 autonomous drills amongst current operations.

\(^{19}\) Sources: Rio Tinto / BHP BMA (Peak Downes) / Newmont Boddington Gold Mine
A.2.2 Benefits

The main benefits identified include:

• yield gains
• efficiency (continuous operation without shift changes)
• controls the dispatching of machines based on the production plan and availability of load points and dump points
• fewer waste products given more targeted digging
• evaluation software to analyse productivity of digging operations
• reduced number of grade checkers
• reduced Lost Time injuries (LTI's) due to machine/human interaction
• reduction in double handling
• working life of machinery is increased
• machine operated remotely
• reduction in operational costs
• production and condition monitoring reports easily generated from control systems tracking the precise excavation / drilling procedures.

A.2.3 Productivity Estimation

In 2008 it was estimated that selective mining technology was being used by about 15% of open cut mines in Australia (The Allen Consulting Group, 2008).

The ability to target ore bodies and minimise wastage is producing perceived benefits of up to 10% of total productivity.

Given the emphasis on machine guidance, mining operations can withstand difficult conditions (i.e. poor visibility) and increase production in scenario’s where previously operations would be heavily impacted. This has a direct impact on the productivity of the mining operation by minimising down-time associated with poor conditions. Within Australian conditions this is particularly relevant given the extremities of both storms and heat in many mining regions.

A.2.4 Adoption Costs

Mining companies have invested heavily in automation technology over the past decade as is evidenced by Rio Tinto’s ambitions ‘Mine of the Future’ program that is now coming to realisation.

Various mining companies and their subsequent operations have vested heavily in the automation process, to millions of dollars, with some now realising benefits through either full or semi-automation processes. Typically, GNSS comprises a small component of overall costs and will generally involve capital expenditure of approximately $50,000 to setup an appropriate localised GNSS base station, with costs of approximately $30,000 for the installation of
compliant individual GNSS receivers in connecting machinery. It is important to note that investment into the actual positioning component of automation is quite minimal in comparison to the overall costs of implementing fully automated systems.

### A.3 Offshore Positioning (Oil and Gas Exploration)

Offshore oil and gas production and exploration is a key area of industry that requires precise positioning to facilitate multiple facets of project lifecycle, but is largely centric to the exploration process. The types of exploration activities that are predominantly supported are Seismic and Bathymetric surveys which both contribute to the overall geophysical assessment of potential and existing hydrocarbon deposits.²⁰

Woodside as an oil and gas company is essentially spatial in nature and completely reliant on correct spatial information for geophysical analysis of offshore exploration leases. Woodside itself typically operates at 90% involvement within commitment to offshore activities which includes both the exploration component and also the construction and maintenance of pipelines and plant connectivity to facilitate production stages.

Precise position is typically adopted at the decimetre level utilising Differential GPS (DGPS) corrections delivered by satellite communications as opposed to the cm level positioning associated with RTK. Such corrections are typically supplied via private operators via satellite communications to resolve positional integrity. Whilst DGPS is the primary service utilised under exploration activities, however there is a small reliance on RTK systems for important shore crossing / transition zones for pipeline connectivity. The reliance of independently operated RTK base stations for such activities is particularly important given the increased requirement for accuracies for construction and management of pipelines.

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²⁰ Sources: Woodside
Whilst Woodside itself is the project developer for Oil and Gas offshore fields, the precise position application is more often captured through the operation of service providing companies (such as CGGVeritas, Fugro or Western Geco). Such service providing companies, whom directly conduct the exploration surveys, utilise precise positioning to more efficiently operate and conduct the survey, integrate geophysical datasets spatially (allowing real-time quality control) and minimise the risk of downtime. Integrated positioning is further combined in an overall navigation network (above) which positions hydrophone streamers behind the vessel and allocates them to certain ‘bins’ within the survey area. The ‘binned’ area is an indication of completeness of the survey and is used to evaluate the optimal survey routes and improve efficiency.

Woodside commissions approximately $100 million worth of exploration surveys per year with costs of lost production (A typical survey vessel (Seismic) will be charged out in the vicinity of $700k per day in production) totalling millions in lost revenue of operational cost. Therefore the integrity and reliability of the navigation and positioning surveys is paramount to the efficiency and productivity of operations and as such multiple systems are often integrated amongst an overall navigation system to ensure reliability.

**A.3.1 Benefits**

The benefits identified were:

- Reduced timeframes and improved efficiency for data acquisition
- Full integration of GNSS with nav/positioning systems
- Improvement in reliability and uncertainty of positional accuracy (improving efficiency of exploration process).
- Reduction in positional uncertainty for delivered data
• Reduced operational costs

**A.3.2 Productivity Estimation**

The measure of productivity is best quantified by the delivery of more reliable, accurate spatial data to improve the exploration process. The minimisation of downtime through exploration operations is essential in evaluating the productivity gains. Woodside’s investment in exploration survey equates to approximately $100 million per year and current downtime estimates predict that of this $100 million, 10% is lost to downtime, with a proportion of this being attributable to poor navigation data and/or inefficiencies relating to the accurate steerage of survey coverage.

Productivity is also realised through the evaluation of datasets in real-time via the assessment of positional information and its quality which is aided via correctional information sent to the vessel via satellite communications.

**Figure 3** Integrated positioning system software capturing survey information across offshore prospect region

Data source: Woodside

**A.3.3 Adoption Costs**

For companies like Woodside, adoption costs were largely carried by service providers. Investments in overall navigations systems, incorporating GNSS technologies, have been vast as to improve the reliability and efficiency of the survey process.

Whilst current systems produce certain accuracies at the decimetre level, there is a renewed focus in the offshore survey world of improving the positional accuracies associated largely with height, which is seeing increased investment into the precise positioning services (largely DGPS) that support surveys.
Height has been of particular interest given that previously bathymetric data was related to the Mean Sea Level and dependant on tidal correction models. With improved positioning technologies, the height component of datasets acquired can be related to a more consistent mathematical surface and ensure greater consistency.

### A.4 Mine Site Surveying

Site surveying across mining operations is central to many processes and has always been prevalent amongst exploration, pit, underground and construction operations over the entire course of the project lifecycle.

BHP Billiton in the construction of the Jimbelbar mine Located 40 kilometres east of Newman, has partnered with Sinclair Knight Merz to provide operational survey support as the project moves through its development phases. The development work encompasses a new ore processing plant, the procurement of mining equipment and new rolling stock to deliver massive capacity growth over the next four years.

Jimbelbar is also part of an expansion project, launched in 2010 aimed at increasing production from the Pilbara mines to 240 million tonnes of iron ore annually by 2013. The expansion of Jimbelbar, together with an expansion of the inner harbour at Port Hedland and works on the duplication of rail tracks is estimated to cost $2.15 billion.

Figure 4  **Mine site surveying using augmented positioning**

These projects require significant survey services to assist in the design and construction of all infrastructure associated with the iron ore processing plants.
To support site specific activities, localised GNSS base stations feeding RTK corrections have been setup to coordinate site activities in regards to surveying and construction. Multiple on-site surveyors coordinate to the reference station and provide survey services in regard to set-out, asset management, volume estimates, as-built information and design to multiple project departments.

Construction, via machine guidance, is also facilitated through integration with centralised base stations, with productivity benefits being realised over controlled earthworks, equipment graders, digger etc.

Figure 5  Construction layout

Another area associated with mine site management is loading systems and yard management as material is transported from one area to another. Again, this process is heading towards automation through the integration of positioning with loading machinery improving efficiency of transportation and allowing management of material volumes.

A.4.1  The adoption of augmented GNSS amongst site surveying

The areas where adoption has occurred include:

- Coordination of survey control
- Survey of all composite services mapping
- Topographical and feature survey for design
- Progressive ground model surveys during construction to assist in the volumetric surveys for contractor payment
• Set out of design
• Set out of various boundaries
• Survey of cleared areas
• As constructed surveys

Benefits
The benefits identified are:
• Instant connection to site control
• Efficiency in site survey updates (Construction, Utilities and Services)
• Reduced on-site surveyors required for data capture as site is developed
• Construction contractors can connect directly to localised control and upload digital plans as they are developed.
• Interoperability between survey and construction
• Real-Time material tracking and stockpile management
• Reduced operational costs

A.4.2 Productivity Estimation
The productivity benefit estimation is mainly realised through reduced labour costs and accounts for anywhere between 30-40% (Illia Milan SKM Survey Team Leader). This is in comparison to more traditional surveying methodologies previously adopted for site surveying duties, which would more often than not require the presence of a senior surveyor and an assistant.

The requirement to only use one surveyor for the majority of tasks and the increased efficiency of GNSS technology in supplying real-time position information at cm level is the key realisation of benefits.

Reductions in labour costs are quite significant in Australia due to the remote operations, high remuneration and the requirement to often support Fly-in Fly-out workers.

Adoption Costs
Initial investment in sufficient GNSS equipment is in the order of $500,000; however this is inclusive of multiple receivers operating off continuously operating reference stations. Ongoing costs are minimal after initial investment with full upgrade costs encountered approximately every 5 years.

A.5 Emerging Technologies – Locata JPS
One of the challenging confrontations with mining operations is the supply of ubiquitous positioning across the pit environment. As operations commence in deeper pit environments, GNSS coverage deteriorates due to signal obstruction, resulting in increasing poor performance for machine guidance systems and increasing levels of downtime.
“Using even the most sophisticated and current GPS technology available, we still cannot overcome the issues at the bottom of an open cut mine caused by lack of satellite visibility and multipath.” (Carr 2012)

One technology that may assist in the improvement of ubiquitous precise positioning is that of Locata JPS (Jigsaw Positioning System). Locata JPS is an emerging technology developed to augment existing GNSS coverage with terrestrial based repeated signals, effectively recreating a ground based positioning constellation that is installed at various locations surrounding the edge of a deep pit which is obstructing satellite coverage.

Locata is capable of covering specific areas in a single pit or multiple pits on a mine site to augment satellite derived positions through GNSS and increase effective positioning coverage.

The system is built has two major components, the LocataLites (transmitters) are positioned around the mine pit; and the Jps Receivers mounted on the machines (i.e. Automated Drills). The network of receivers is referred to as the ‘Local constellation’, or terrestrial network. This terrestrial network is integrated with GNSS satellite constellations to provide a more precise position option to the in-pit operations.
JPS is currently being trialled at Newmont Boddington Gold Mine (Western Australia), with performance and benefits being closely evaluated. The application of precise positioning is largely associated with the Newmont drill fleet which is fully automated and reliant on positioning availability from the combined GNSS + JPS system.

Results suggest that the reliability of positioning coverage through this augmented positioning service is as dependable at the 92% - 99% level, even in deep pit environments. This is a distinct improvement over the varied GNSS only availability of between 10% - 85% coverage.

**Benefits**

The clear benefit of augmenting GNSS with terrestrial based positioning networks is to maximise the effective precise positioning coverage around difficult environments that obstruct satellite borne signals.

- Reduction of downtime (equating to approximately $1000 per hour for each drill)
- Downtime decreased by 112.7 hours, approximately $112,700 over two month trial period.

**Adoption Costs**

Whilst the Locata JPS based system is still in the infancy stages of development, it is expected that this system (and similar augmenting terrestrial based positioning systems) will become common place across mining operations which are becoming increasingly dependent on automated processes.
Typical hardware costs to purchase both receivers and transmitters would be required and it is estimated that this would be priced up to the $500,000 mark dependent of course on the area of coverage and the number of machines reliant on the positioning.
Appendix B  Social and Environmental Benefits

Additional key benefits that are derived from precise GNSS are those in regards to health and safety aspects of mining operations, with positioning becoming particularly crucial to mitigating and managing risk across operations.

Further applications emerging from both automation and advanced positioning, include collision avoidance systems which further act to mitigate on-site risk by taking control away from human operators.

With increased emphasis on the health and safety aspects of mining operations, positioning is becoming particularly crucial to mitigating and managing risk across operations.

The concept of automation, again, is of increasing significance to mining health and safety, especially as it becomes further integrated in the coming decade. By reducing the actual number of on-site labour (through automation) within dangerous pit or underground environments there is a simple risk reduction in potential hazards. Whilst no direct numbers can be quoted for the potential reduction in LTI (Lost Time Injuries), this is certainly a KPI for trial evaluations of automated systems.

Further applications emerging from both automation and advanced positioning, include collision avoidance systems which further act to mitigate on-site risk by taking control away from human operators.

Environmental management through efficiencies such as reduced wastage, more effective material management and reduced fuel are of also of high significance to operations. The spatial relationship between data collected on-site, including contaminants, wastage and processing by-product are continually being collated and used to base intelligent management decisions and minimise environmental impacts.

The availability of precise positioning is also aiding in the capture and collation of spatial data sets used to evaluate social issues such as heritage across proposed mining lease areas. A particular example of this is the multi-criteria spatial analysis (via GIS) performed by the Snowy Mountains Engineering Company (SMEC) to determine suitable land use for identification of heritage sites across a major CSG pipeline route.

Information was gathered from a combination of existing data sources (Department of Natural Resources) and specialist heritage assessment teams who used mobile mapping applications to map vegetation / landscape and aspect across a major CSG pipeline corridor (Chinchilla to Gladstone).

The provision of centre-meter accuracy, to the location of cultural heritage sites and individual finds will provide them a greater level of protection.
through a more complete understanding of the site and its surrounding topography.

Access to high resolution positioning system data may even be utilised to determine the accumulating effects of foot traffic, bushfire and external environmental events in and around specific less known or some of the more visited sites. Human influence on the terrain combined with natural weather conditions may contribute adversely to further rapid degradation of sites in general.

Accurate sub-meter data can be utilised as the basis of plans for mitigating the effects of tourism and rainfall runoff in the areas within and adjacent to heritage sites. The implementation of infrastructure such as roads, pipelines or railways may have an adverse effect on adjacent cultural heritage sites. By utilising high accuracy Digital Elevation Models (DEM), simulations such as flow direction models, weathering profiles and human influence can be modelled prior to infrastructure construction approvals.

The use of sub-meter data may be traditionally thought of as not being useful at this scale, for use in a Cultural Heritage environment. However, it has proven to be useful in the evaluation of anthropogenic influences in other areas of the world containing historical sites.

Studies of Cultural sites in other countries have attempted to map various environmental aspects, such as fungus identification, measurement and mapping and the assessment of influencing climatic conditions and their potential impact on the artefacts. Researchers have found that the simple act of installing a road, which creates an impermeable surface and prevents the rainfall runoff from being absorbed. Directing the runoff to new areas contributes to changes in the concentration of groundwater levels relative to rock surfaces. The water, which contains salt, will in turn contribute to the deterioration of the rock structure. This can be particularly evident in sandstone.

Mapping of environmental changes, natural or anthropogenic, in and around Cultural Heritage sites, assists in the assessment and planning of protection and preservation methods. Unfortunately, high accuracy measuring systems are required to provide meaningful data, yet these are not available due to the majority of sites remote locality and the cost of implementation. Sites already known to be at risk from a variety of negative factors may have their life extended through effective mapping, planning and the introduction of procedures to mitigate current threats.
Appendix C  Level of Adoption

In regards adoption across the sector, the level of adoption varies including the application to which positioning is used. Information gathered from industry would suggest that adoption levels sit between 15 and 60 per cent\(^1\) across the sector, with near full adoption in the areas of mine site surveying and minerals exploration. This adoption percentage is also supported by recent reports, with the Allen and ACIL Tasman Reports (2008) indicating that adoption levels for mining are likely to be in the vicinity of 11 to 30 per cent in 2012.

The mining industry is looking into a future of increasing global demand for many of its products, but is constrained by resource grades, energy, labour, and safety, environmental and capital and working-cost considerations. It could be argued that the current outlook is not dissimilar to that of the previous century, it is only the level of technology that was appropriate then, as compared with now, that guides the solution strategy.

Given these challenges there have been various technological initiatives, from early open-pits in the 1900’s right through to automation, autonomous vehicles, and ultimately, the autonomous mine. Pukkila and Sarkka (2000) discuss the evolution of mining, starting with the ‘modern mine’ moving to a ‘real-time mine’ and ultimately evolving into an ‘intelligent mine’.

Figure 8 below shows this evolution and the accompanying development of autonomy, from simple user-interface and monitoring development, through to more complex aspects of perception, position, navigation and mission planning technologies.

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\(^{21}\) Personal Communications Gavin Yeates - BHP Billiton
The incremental evolution is indicative of the adoption of positioning technology where step changes are being made incrementally as the technology becomes available. Consultation with industry suggests that whilst mining has been an early adopter of positioning technology, notably being used for minerals exploration and site surveying, full adoption and augmentation across all applications by the sector is possibly still some years away with the incremental approach likely to continue. Projecting forward to 2020, it is very likely that this adoption level will increase dramatically across a number of operations, however the level of adoption can be somewhat constrained to a few limiting influential factors discussed below;

**Ubiquitous Positioning**

Given that GNSS is not used as a primary form of guidance and is more or less an augmentation to existing inertial and radar sensors, improvements to GNSS coverage and integrity will see a greater rise in adoption as users build confidence in its reliability. It is clearly integrity, availability and reliability of positioning through GNSS that will improve adoption of automated systems. This is also inclusive of developments into indoor (underground) or heavily obstructed deep pit positioning which will facilitate a ubiquitous guidance mechanism that allows full confidence in automated processes.
System Interoperability & Standards

Primary to all aspects of positioning application amongst mining operations is the system interoperability. Many existing mining operations are purchasing ‘off the shelf’ positioning systems that are not fully integrated with the vast majority of applications the positioning could potentially support. When greater interoperability is achieved, adoption of positioning techniques and technology will be applied more seamlessly and to a wider array of tasks allowing more standardised applications to be developed and used across the sector.

Lack of industry safety standards to support antonymous operations

Many of the new applications will require safety standards and policies to be rewritten. While standards setting can be a drawn out process it is also an ongoing task where technology is changing. Nevertheless the time required for revision to safety policies and standards has to be taken into account in assessing the rate at which the technologies mentioned above are likely to be implemented.
Appendix D  Sources

D.1  Citations


Seymour C. 2005, *Applications for GNSS on Shovels and Excavators*.


**D.2 Websites:**


