The value of augmented GNSS in Australia

An overview of the economic and social benefits of the use of augmented GNSS services in Australia

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Executive summary

Global Navigation Satellite System (GNSS) refers to constellations of satellites that provide a signal that enables users to determine their position anywhere outdoors. Augmentation services (augmented GNSS), which provide greater accuracy and reliability to the signal, are delivering significant economic benefits in several key sectors of the economy, as well as environmental, safety and other social benefits. Further adoption of augmented GNSS services by industry, and new thinking about how to apply them, offers the promise of further economic and social benefits in the future.

This report provides an overview of economic and social benefits, experience, and prospects for the use of augmented GNSS in agriculture, mining, construction, utilities, surveying and land management, road transport, rail, maritime, and aviation activities.

Economic benefits

Augmented GNSS services have delivered economic benefits to Australian industry through improvements in productivity and more efficient use of resources. On the basis of the findings of this report it is estimated that:

- By 2012 Australia's real GDP was been between **$2.3 billion and 3.7 billion higher** than it would have been without the accumulated productivity improvements arising from augmented GNSS.
- By 2020 our projections are that real GDP could be between **$7.8 billion and $13.7 billion higher** than it would otherwise have been.

The overall macro-economic impacts of the productivity improvements derived from augmented GNSS are summarised in Table 1.

Table 1 **Economic impacts**

	2012 low	2012 high	2020 low	2020 high
	$m	$m	$m	$m
GDP	2,288	3,717	7,832	13,715
National income	1,633	2,670	5373	10,115
Private consumption	560	853	2,630	5,904
Investment	623	1,010	2,111	3,717
Exports	1,211	1,986	3,884	5,833
Imports	240	344	1,229	2,560

Note: All amounts in $2012

Data sources: ACIL Allen, SKM, Lester Franks

Real income is estimated to have been higher by between **$1.6 billion to $2.7 billion in 2012.** This is projected to increase to between **$5.4 and $10.1 billion by 2020**.

A significant result is that the productivity improvements are estimated to have increased net foreign trade by between **$1.0 billion and $1.6 billion** in 2012.

Sectors

The greatest economic impact from the use of augmented GNSS is in the agricultural, mining, construction and surveying sectors. The utilities and transport sectors have also realised important economic benefits through improved asset management and logistics.

The greatest economic benefits in 2012 were derived from the use of augmented GNSS in surveying, machine guidance, automation of operations and asset mapping. The levels of accuracy required for these applications varies from 2 cm to 10 cm. High reliability is also necessary where safety is concerned.

Savings for surveying of between 20 to 40 per cent of labour costs were reported in case studies and research. Savings in costs of between 10 per cent and 20 per cent are also reported from applications of machine guidance and automation in mining and construction. Automated mining is reported to deliver overall productivity gains of up to 15 per cent.

The use of machine guidance for controlled traffic farming in the grains industry has been reported to deliver savings in labour and fuel costs as high as 67 per cent and 52 per cent respectively. This was accompanied by a 68 per cent increase in gross farm margin.

Transport and logistics has been an important user of augmented GNSS. Its use in fleet management has the potential to reduce fuel consumption by around 10 per cent according to our research. At ports it has delivered cost savings of around 30 per cent in improved container management and handling.

Electricity, water and gas utilities also use augmented GNSS for asset mapping where total cost savings of between 5 and 10 per cent have been reported.

Augmented GNSS is used in the aviation and maritime sectors for navigation purposes. It delivers operational cost savings to both sectors through more efficient routes lowering fuel costs. It is important for piloting ships in ports and port approaches.

Realisation of the additional benefits reported for 2020 will depend on several factors. Firstly, it will require the extension of augmentation services to fill gaps in coverage. Greater compatibility between systems will also help.

Secondly, it will require an increased pace of adoption. This could be driven by further demonstration of the benefits of augmentation services in practice which in turn builds greater confidence in to potential users.

Thirdly, it will require ongoing integration with other systems such as geographic information systems (GIS), sensors, vehicle mounted cameras and applications that process location information.

Emerging location based applications

The use of machine guidance supported by augmented GNSS in both the mining and the construction sectors has significant potential for further economic benefit. Automated mining is seen by one industry leader as revolutionising the way large scale mining is done, creating hi-tech jobs and helping miners improve safety and environmental performance.

Development of ground based radio positioning systems that offer the potential to deliver localised GNSS in deep pits, underground and in tunnels will be important for the wider use of augmented GNSS in the construction mining and transport sectors.

The emergence of Cooperative Intelligent Transport Systems (C-ITS) is expected to find further application of augmented GNSS systems in managing traffic movements and linking road users to the road environment through real time sharing of information of vehicle and infrastructure status, road traffic conditions and potential hazards. The availability of vehicle positioning is critical for many potential C-ITS applications and in particular with safety-of-life applications.

An important development is the use of augmented GNSS with vehicle mounted cameras and remote sensing for rapid acquisition of location related data. The use of Unmanned Aerial Vehicles (UAV) to rapidly and repeatedly capture high volumes of asset information is currently being trialled by some power utilities.

Future developments in the application of augmented reality offer potential for improved community consultation at the planning stage of major infrastructure developments. This has important implications for the interaction between the community, planners, architects and engineers in planning new developments.

Augmented GNSS can improve the way industries operate and provide new approaches to operations and asset management. Those who think ahead of the pack will do well from finding further advances made possible by the use of augmented GNSS.

Environmental and social benefits

Augmented GNSS has also delivered important social and environmental benefits. It can support better water management on farms and in mines where higher accuracy in mapping and control systems assist managers in increasing water use efficiency and in managing the impact on water resources more effectively.

Through more efficient asset mapping and better management of construction, it reduces the impact of maintenance and construction activities on the community.

It assists the mining sector with more accurate environmental monitoring and better materials handling to reduce the environmental footprint. It has been used by the petroleum sector for accurate location of cultural heritage sites to ensure that the routes for pipelines and other infrastructure do not damage these sites.

Improved route planning and cooperative intelligent transport systems help reduce traffic congestion, lower fuel consumption and emissions and reduce the level of interruption from road maintenance. More efficient surveying also helps the investigation and design process to minimise the impact of planned developments on the environment.

An important role for augmented GNSS is in safety of navigation and minimising the risk of aviation and maritime accidents. This is particularly important to reducing the risk of oil spills and protecting areas of high environmental value such as the Great Barrier Reef Marine Park.

1 Introduction

ACIL Allen Consulting, in partnership with SKM and Lester Franks Surveyors and Planners, was 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 project is to provide an understanding of the economic and social benefits of precise positioning information in Australia. This information will 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.

This report provides an overview of the economic and social benefits. Nine separate reports are available which provide more detail on the sectors considered in this overview.

1.1 Report structure

Chapter 2 of this report provides a brief review of the findings of the sector reports and reviews emerging applications.

Chapter 3 discusses emerging location based services and Chapter 4 outlines the nature of GNSS and augmented GNSS.

Economic impacts are discussed in Chapter 5 and social impacts are discussed in Chapter 6.

The methodology for developing the estimates of the benefits is included Appendix B.

1.2 Summary of economic and social impacts

1.2.1 Economic

Augmented GNSS services have delivered economic benefits to Australian industry through improvements in productivity and more efficient use of resources. On the basis of these findings it is estimated that:

- By 2012 Australia's real GDP was between **$2.28 billion and 3.72 billion higher** than it would have otherwise been without the accumulated productivity improvements arising from augmented GNSS.
- By 2020 our projections are that real GDP could be between **$7.83 billion and $13.72 billion higher** than it would otherwise have been.

The largest impacts have arisen in the agriculture, mining, construction, surveying and land management, utilities and road transport and handling areas. The higher outcomes projected in 2020 assume wider coverage of augmentation services and include some speculative applications in the high case. Further details can be found in Chapter 5.

1.2.2 Social and environmental

Augmented GNSS delivers other important social and environmental benefits. This includes increased safety for mine and construction workers through the use of machine guidance and automated systems that remove operators from dangerous situations and from exposure to dust and contaminants.

It is also used in mapping of heritage sites and coastal regions which is important for improved and more sustainable environmental management.

Cooperative Intelligent Transport Systems (C-ITS) have the potential to significantly reduce fuel consumption and emissions while also providing the driver with more information on potential hazards, accidents and road congestion.

Positioning technology allows more efficient application of fertilisers, in turn reducing chemical run-off. Likewise it can help minimise the impact of mining operations on the environment through better management of materials handling and more accurate monitoring of potential hazards such as leachates from tailings dams. Further details can be found in Chapter 6.

2 Sector impacts

The individual sector reports address the application and economics of augmented GNSS in detail. This section provides a brief overview of the findings.

2.1 Common themes

The sector studies demonstrated that augmented GNSS can improve the way industries operate and provide new approaches asset management. Those who think ahead of the pack will do well from finding further advances made possible by the use of augmented GNSS.

2.1.1 Synergies between sectors

There are significant synergies between some sectors in their use of augmented GNSS. This includes the need for precise positioning for surveying, machine guidance, autonomous haul vehicles and for asset management.

Precise position information is important to the surveying, construction, utilities, mining and transport sectors. The underlying driver of this is the need for accurate benchmarks and reference points, maps and baseline information upon which many management activities and control systems are based.

In construction and utilities for example, the basic survey and set out data, once captured, forms a platform on which asset management systems, maintenance systems, fleet management and cooperative intelligent transport systems are established. Integrity monitoring is often as important as precise position and this requires augmented GNSS.

All of these applications delivered significant economic benefits for the mining, construction, utilities and transport sectors.

2.1.2 Adoption rates vary

The rates of adoption across the sectors studied vary considerably. The sectors concerned with creating and managing physical assets have been at the forefront of adoption. This has been led by the surveying sector, the mining, construction, utilities, and transport infrastructure. These industries manage large capital investments and efficiently managing and maintaining assets has driven adoption.

The grains industry has also been a strong adopter in agricultural sector. Adoption rates in other agricultural sectors such as horticulture, viticulture and even beef and dairy have not been as high.

The aviation and maritime sectors use augmented GNSS for navigation. The principle application in the rail sector has been in track surveying.

Opportunities exist for its use in train management systems for long haul routes.

Early stage adoption can be a difficult due to the risks involved in implementing new technologies. However once a sufficient number of proven uses is established, the demonstration effect can help accelerate adoption. Realisation of the potential economic benefits identified in this report will depend on building greater confidence in augmented GNSS systems.

2.1.3 The demand for accuracy and integrity

The potential for greater accuracy is known but its use is emerging slowly. Higher cost is a factor where greater accuracy is optional, but the awareness of applications that draw on greater accuracy is growing. For example inter-row sowing in the grains industry requires more than decimetre accuracy. Cooperative Intelligent Transport Systems are also emerging that will require greater positioning accuracy than was required previously.

In many cases reliability and integrity can be as important as accuracy. This is the case in navigation, machine control, container handling at ports, automated train management systems and fleet management systems.

2.1.4 The need for compatible systems

Incompatibility between different augmentation systems was identified as an issue in the mining sector and is potentially a limiting factor in land transport systems. It is seen as an issue in areas as diverse as mapping the land/sea interface to mining.

The expanding CORS network has been instrumental in providing seamless positioning across different enterprise activity areas. However gaps in the system, interference from buildings and vegetation and problems in deep mining pits and underground, limit the potential to use augmented GNSS in all situations.

New and emerging technologies are seeking to fill these gaps. Development of new GNSS systems will also broaden the geographic range of precise positioning services. As these emerge, incompatibilities between systems may be a limiting factor to wider adoption.

2.2 Key findings

2.2.1 Agriculture

Output in the agriculture sector was between $298 million (0.9 per cent) and $466 million (1.4 per cent) higher in 2012 as a result of the use and application of augmented GNSS in the grains industry and elsewhere.

By 2020, output is projected to be between $885 million (2.5 per cent) and $2,185 million (6.2 per cent) higher with further adoption in the grains and livestock industries.

The economic benefits in cropping from the application of precision agriculture supported by augmented GNSS are large, enabling recovery of investment rapidly, sometimes within less than two years.

Adoption rates in agriculture fluctuate considerably depending on seasonal factors. A farmers' ability to invest in on farm productivity improvement depends on a good season. The highest adoption levels have been in the grains and cropping.

Applications in the grains industry include automatic guidance and controlled traffic farming, variable rate fertiliser application and inter-row sowing. Cost savings of around 67 per cent in labour and 52 per cent in fuel are reported. Overall productivity gains are estimated be range from 10 to 20 per cent.

Adoption rates in the livestock and horticulture and viticulture areas have been slow to develop.

Accuracy requirements for precision agriculture have traditionally been around 10 cm. New applications such as inter-row sowing will be assisted by extension of GNSS augmentation services at the 2 cm level of accuracy. This could be achieved for example through the expansion of CORS networks in Australia.

Augmented GNSS can also deliver considerable environmental benefits, particularly in more efficient use of water and minimising chemical runoff.

2.2.2 Mining

It is estimated that output from the mining sector was between $683 million and $1,085 million higher in 2012 than it would otherwise have been as a result 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.

The mining sector has been an early adopter of precise positioning technologies with productivity benefits arising from operational efficiency improvements, including the reduction of operation costs and waste.

Whilst stand-alone GNSS technologies are widely implemented in many applications, they are not the sole positioning system used due to limitations of reliability and availability of signal in some circumstances.

Mine site surveying supported by augmented GNSS has been an important beneficiary of precise GNSS where accuracies of around 2 cm are required. Augmented GNSS has reduced the labour cost of mine site surveying activities by between 30 and 40 per cent.

Geophysical surveys also draw on augmented GNSS. The cost of down time for seismic vessels is reported to be reduced by around 10 per cent as a result of the use of precise positioning.

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. The main benefits from the use of augmented GNSS are significant operational efficiencies in reduced labour, reduced fuel costs and increased yield gains. Automated mining is reported to deliver overall productivity gains of up to 15 per cent.

Future benefits will depend on further expansion in the availability of precise positioning technologies of which augmented GNSS is at the centre. Greater consistency between systems will also encourage adoption. Augmentation technologies that operate underground will also be required.

Other benefits from the use of precise GNSS include higher safety in mine operations to improved cultural heritage and environmental management.

2.2.3 Construction

Output from the Construction Industry is estimated to be between $448 million and $723 million higher in 2012 as a result of the use and application of augmented GNSS in activities such as site surveying and machine guidance.

This could rise to between $1430 million and $2,507 million by 2020 with further adoption of augmented GNSS supported applications and expansion of GNSS services.

Precise location plays a critical role in the construction sector. It facilitates the efficient flow of data across construction and engineering activities. Increasingly larger scale infrastructure projects incorporate augmented GNSS positioning across the complete project design to construction lifecycle and on into asset management once construction is completed.

Major applications include surveying (both detail and set out), machine guidance and asset management. Most of these applications require accuracy of around 2 cm although some can operate with accuracies at 5 cm. Asset management in the construction and the utilities sector generally requires 10 cm accuracy. Productivity benefits are significant.

Labour requirements for construction surveying can be reduced by between 20 per cent and 40 per cent. Machine guidance enabled with augmented GNSS has the potential to deliver a 10 per cent reduction in total project costs and subsequent asset management. Adoption levels across the industry are high, up to 40 per cent in construction. Adoption is expected to increase significantly in the next 10 years.

Gains in the future will depend on increased use of existing technologies augmented by further innovation in systems and wider availability of augmented GNSS.

Extension of the CORS network would underpin the higher outcomes. The densification and improvement of both accessibility and reliability of CORS networks would give greater confidence to many construction operations (such as automated machinery).

2.2.4 Utilities

Output from the utilities sector is estimated to have been between $50 million and $82 million higher as a result of the use of augmented GNSS in asset management and maintenance. With further adoption in asset mapping and control systems this could increase to between $175 million and $307 million by 2020.

Precision positioning plays a critical role in supporting asset mapping and management and control systems for utilities. Accuracies of around 10 cm are currently required.

Precise positioning has contributed savings operating and maintenance costs associated with the development and management of the utility assets. Overall costs have been reduced by around 10 per cent.

Realisation of further savings will depend on future levels of adoption, further innovation in related spatial technologies and expansion of GNSS augmentation services.

New technologies are likely to include improved GNSS services and receivers, mobile mapping technologies, remote sensing techniques and advanced surveying and setting out systems.

Compatibility between future augmentation services will also be required for these outcomes to be realised.

2.2.5 Surveying and land management

Surveyors' use of augmented positioning tends towards the precise end of the spectrum, with precision at the cm level normally required. Whilst some surveying applications require lower precision, for example in the order of a decimetre, generally this precision requires precision tools and techniques.

The use of augmented GNSS is extensive in the surveying industry. Augmentation signals are provided through stand-alone RTK systems, CORS networks and space based augmentation services.

Precise GNSS is already being applied in engineering and construction surveying and is finding further applications in regional surveys, infrastructure surveys, see level monitoring and sub-division and land development activities.

The use of precise GNSS with innovations in geospatial technologies is delivering significant productivity gains. Tasks that traditionally took weeks can now be completed in days.

Future levels of adoption will depend on the extension of augmentation services across the country. This could include both further developments of CORS networks as well as space based positioning services.

The report estimates that in 2012, augmented GNSS had delivered cost savings to the surveying and land management sector of between $30 million and $45 million. These savings are projected to increase to between $100 million to $150 million by 2020. These estimates are based on conservative assumptions on the rate of development of CORS networks.

Development of GNSS compatible positioning services for areas where GNSS cannot effectively penetrate such as indoors and underground could also contribute to expansion of the use of augmented GNSS by the surveying sector.

2.2.6 Road transport and logistics

The road transport and logistics sector has benefited from the use and application of augmented GNSS. Combined output from these sectors is estimated to have been between $ 154 million and $213 million higher in 2012 as a result of its use.

By 2020 output is projected to be between $534 million and $916 million higher as a result of greater use in Cooperative Intelligent Transport Systems and freight and container management at ports and transfer nodes.

Positioning across the transport sector has many applications including freight and logistics, vehicle charging, intelligent transportation systems and container management.

Accuracy requirements in road transport and logistics range from 10 cm for general transport logistics to 2 cm for container management at ports. However, all application require high levels of reliability and increasingly interoperability across multiple systems.

Significant improvements in productivity have been realised from the use of augmented GNSS in transport applications. Further improvements are possible. Their realisation will depend on future levels of adoption, further innovation and extension of augmented positioning services.

2.2.7 Rail Transport

The most common use of augmented GNSS in the rail sector to date has been in surveying track, signal and transponder placement.

There is potential for precise GNSS to support Automatic Train Management Systems (ATMS). The Australian Rail Track Corporation (ARTC) is investigating the use of such systems for its longer distance track infrastructure and systems.

The metropolitan rail systems have however adopted the European Train Control Systems (ETCS) which relies on in track transponders and do not use precise GNSS for positioning.

The rail sector requires 2 cm accuracy for surveying of track and location of signalling and transponder infrastructure. High resolution GNSS is also needed for automated stevedoring at ports and, after some hurdles are overcome, might be deployed in rail terminals with a similar efficiency gains.

Positioning technology is being developed for automatic train management, which will allow wayside signals to largely be replaced by in-cab signalling. Most of this (outside metropolitan areas) will require augmented GNSS for integrity monitoring and reliability criteria.

Allowing trains to be safely operated closer together would have system wide capacity benefits. Such developments are still some way off in the Australian rail sector.

2.2.8 Maritime

Augmented GNSS is required, along with other electronic and radio navigation technologies, for navigation in confined waters and environmentally sensitive areas such as the Great Barrier Reef and Torres Strait. The principle benefits of the use of augmented GNSS in maritime activities are in improved safety of navigation and reduced risk of maritime accidents and oil spills.

The use of augmented GNSS has delivered productivity benefits in ship operations and in navigation safety. There are also benefits from the use of augmented GNSS in offshore oil and gas operations and in bathymetry.

Ships require horizontal accuracy of 10 metres for general navigation and 1 metre in ports and confined waters. Automatic docking and offshore construction activities require cm accuracy.

Reliability and integrity of position signal from GNSS is also critical to marine navigation especially in and around ports, confined shipping lanes and areas of high environmental value such as the Great Barrier Reef Marine Park.

The demand for augmented GNSS is likely to increase as developments in e-navigation are implemented over the coming decade. It has been estimated that e-navigation could to improve navigation decision making by officers on the bridge by a factor of 10.

2.2.9 Aviation

Global Navigational Satellite Systems (GNSS) are increasingly being used in all sectors of the aviation industry as an aid to navigation. Regulatory authorities have acknowledged this trend and incorporated GNSS in regulatory policy and procedures.

Aircraft navigation does not generally require high position accuracy for lateral guidance. The accuracy available from stand-alone GNSS when operating properly is sufficient for most situations.

Integrity is more important with around 4 nautical miles required over ocean, 2 nautical miles over land and 0.3 nautical miles required for non-precision approaches. Precision approaches require integrity of around 40 metres.

Higher levels of vertical positional accuracy are required for precision approaches and landings.

There are two navigation technologies that can be used in precision approaches

- Instrument Landing Systems (ILS) that broadcast a flight path from radio beacons on the airstrip that are received by an ILS receiver in the cockpit
- Ground Based Augmentation Systems (GBAS) that provide augmented GNSS at airports.

GBAS could deliver savings in fuel costs if installed at all major Australian airports. However, other landing systems, including ILS, deliver similar savings. Accordingly little net benefit for airlines in lower fuel costs could be claimed for GBAS.

GBAS would deliver cost savings for infrastructure at airports compared to ILS. However ILS is to be maintained for the time being as not all aircraft are GBAS equipped.

Savings in capital costs to replace terrestrial navigation aids of around $119 spread are possible with RAIMS[1] capable GNSS.

Space Based Augmentation Systems (SBAS) provide augmented GNSS over a wide area. However, the net benefits of an SBAS to the aviation sector alone do not appear to be sufficient to justify the cost.

2.2.10 Finance sector

To date GNSS in financial services have been primarily used in the banking industry for time and date stamping. Accuracy in recording timing of transactions is critically important in relation to large international transfers of funds, where contractual conditions and varying regulations make such records an integral part of the business. Timestamp accuracy to a high degree of

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[1] RAIMS stands for Receiver Autonomous Integrity Monitoring. Further information is contained in the Aviation Report.

precision (in milliseconds) is needed for this application, where timing for completion of contracts or transfers of funds is at times required to be verified accurately.

GNSS devices are also an integral part of security systems in banking and other financial institutions. They are used to track movements of cash in armoured vehicles and estimate arrival times of the cash to bank locations. There are reported instances of GNSS devices in Automated Teller Machines (ATMs) being used to track stolen machines.

In insurance, GNSS is used very widely for tracking, examples include

- checking automotive insurance claims, to verify where a driver claims a vehicle was located
- in relation to weather claims, to track movements of natural objects.

The above applications can be achieved with stand-alone GNSS. Precise accuracy is not a priority for applications in the finance sector.

All elements of the financial services sector with a retail customer orientation (banks, credit unions, other lenders and most insurers) are however increasingly likely to use GNSS applications for retailing in a similar fashion to other retailers: that is, linking to individual users' personal GNSS enabled devices to attract them to storefront promotions and office locations. Augmented GNSS is not required for these uses.

3 Emerging location based services

This report has identified a range of emerging applications across a number of key industry sectors that will benefit from the availability of augmented positioning.

The applications range from intelligent transport systems, machine automation, precision farming and the development and use of virtual built environments and augmented reality. Benefits include improved movement of people and freight, more efficient use of resources and plant and equipment, and better and more informed decisions for design and development of infrastructure.

Realisation of full benefits from some emerging applications will require wider availability of GNSS augmentation services

3.1 Cooperative Intelligent Transport Systems (C-ITS)

C-ITS is an emerging transport initiative that aims to move people and goods more safely and efficiently throughout Australia's road networks[2]. It links road users and their vehicles to their road environment by sharing information, such as vehicle location direction and speed, road traffic conditions and potential hazards.

C-ITS relies on a combination of three enabling technologies: wireless communication; safety monitoring software; and digital maps. The positioning requirements needed for the initial rollout of C-ITS have yet to be finalised. However research overseas suggests that the key parameters will include:

- *Accuracy* – vehicle to vehicle and vehicle to infrastructure - from between 0.5-5.0 metres[3];
- *Integrity* – the ability of the positioning system to identify when a pre-defined alert limit has been exceeded;
- *Continuity* – the capability of the navigation system to provide operational output with specified level of accuracy and integrity;
- *Availability* – the percentage of time the system is available and satisfying all of the above parameters;
- *Interoperability* – the ability of different vehicle positioning systems to operate with some level of minimum consistency in terms of absolute accuracy, hardware, signals and infrastructure;
- *Timeliness* – the ability of the system to update absolute and relative position solutions at the require rates, typically 1 second (1Hz).

2 Austroads research report – Vehicle Positioning for C-ITS in Australia

3 Austroads research report – Vehicle Positioning for C-ITS in Australia

The recent report from Austroads into C-ITS in Australia suggests that the current Australian CORS[4] networks are likely to provide the necessary positioning capabilities, but raises questions on the ability of some commercial services to support C-ITS safety applications.

In addition the sparseness and various business models used for both public and private CORS management cause operational issues and there is the inherent risk that without more coordinated infrastructure development (be it at ground or space borne augmentation) Australia will miss out on many of the environmental, safety and economic benefits that such systems support.

Whilst ITS systems are being realized in Europe, Japan and USA where they have access to Space Based Augmentation Services[5] that can fulfil the positioning requirements of the system, Australia does not currently possess such positioning augmentation levels and therefore is not currently in a position to reliably support the implementation of ITS. However with a more coordinated approach to infrastructure and communication development, including improving access to a wide area augmented GNSS, the benefits of C-ITS may reach its full potential in the future.

The development of CITS systems would contribute to a wide range of economic and social benefits including:

- reduced time travelled
- lower fuel consumption and vehicle emissions
- lower traffic congestion
- higher road safety
- further productivity improvements in logistics
- Development of improved interaction between drivers the transport system with faster responses to accidents and breakdowns leading to lower costs of such incidents and higher levels of safety.

3.2 Mine Automation

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. A key component of the move towards automation is the availability of real-time precise positioning, typically provided by augmented GNSS augmented and other sensors[6].

While mine automation has been in development for a number of years, there is growing recognition in the industry of the benefits of the technology with

[4] Continuously Operating Reference Stations (see section 4.1)

[5] Space Based Augmentation Service (SBAS) uses satellites to deliver augmentation signals (see section 4.1)

[6] Autonomous and remote operation technologies in Australian Mining, November 2011.

the full adoption and commercial use by all miners across multiple sites likely in the short to medium term[7].

Examples of this adoption are provided by the investment in mine automation by large miners such as BHP Billiton, Rio Tinto and Fortescue Metals Group. 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 depend on the successful implementation of these larger scale projects.

Rio Tinto, as part of its Mine of the Future™ program, has become owner of the world's largest fleet of driverless trucks[8]. These will be used in their Pilbara iron ore mines in Western Australia with the aim of reducing costs, increasing efficiency and improving health, safety and environmental performance.

Whilst precise positioning at the decimetre level is critical to autonomous operations, to support needs such as object detection and collision avoidance, there is a much broader adoption of precise positioning, over a range of other applications. The benefits include:

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

Initial trials of semi-automated fleets at the Peak Downes coal mine in Queensland have produced encouraging results for improved fleet monitoring, efficiency and optimisation. Whilst at this stage only semi-automation is being conducted, 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+ fleet.

Uptake of autonomous mining technology will be influenced by economic conditions and the need for companies to gain competitive advantages through investment as well as the compatibility of technologies across industry (McNab and Garcia-Vasquez 2012).

3.3 Machine guidance

Perhaps the most crucial aspect of future positioning applications amongst the mining, construction and engineering industries, is the change to traditional worksite roles. It is now apparent that the role of the surveyor and machine are increasingly intertwined due to the interoperability facilitated by augmented GNSS positioning.

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7 International Mining Auguest2011

8 http://www.riotinto.com/media/5157_21165.asp

As discussed above, autonomous haul trucks are a part of the fabric of mine automation. In construction and engineering, the traditional role of the surveyor in pegging out construction sites (in particular) earthworks has now changed dramatically as machine guidance allows virtual site data to be loaded directly into controlling systems. That is, both surveyor and machine are now part of the same system, whereas previously they operated independently and the exchange of data between the two resulted in lengthy project lag and reduced quality control.

Augmentation of GNSS within positioning applications, largely associated with machine guidance will also continue to improve and facilitate greater automation possibilities as confidence in existing systems develops. Familiarity will play a key part in industry adoption as more and more companies gravitate towards machine guidance and staff are trained in the systems.

In terms of pure positioning objectives, the majority of currently developed systems are at a stage where they are meeting the accuracy objectives of the construction activities, where environments are suitable. In general the accuracy required is 5 cm in the horizontal with high levels of integrity and reliability.

With GNSS modernisation and the growing availability of GNSS signals, individual systems will be able to further support the vast majority of operations across a wider array of environments. Where potential improvement lies, is in the densification and availability of supporting positional and communication infrastructure to help support stand-alone operations and reduce the requirement for significant investment in localised reference stations. With such infrastructure improvement, it is likely that smaller operations will increase their adoption rates of this technology.

Another area of development, particularly from commercial providers, is the improvements to satellite delivered corrections through networks such as Omnistar and the ability of Precise Point Positioning (PPP) to realise similar accuracies to those currently delivered by RTK systems[9]. Currently, PPP can deliver positioning at around the +/- 50 mm level; however the initialisation times required to converge to this level of precision are far greater than current RTK algorithms.

With growing awareness of its benefits to both productivity and safety, machine guidance is becoming a contractual obligation in many infrastructure projects. It is likely that this trend will continue and it will become standard requirement for construction projects.

Further applications not yet conceived will also become dependent on such technology as the ability to realise precise positioning in more trying environments develops. Examples such as precise positioning adoption

[9] RTK refers to Real Time Kinematics which is the basis of the CORS system in Australia.

amongst dredging and pile driving applications are current examples of augmented GNSS being employed amongst a niche sector that previously had no confident way to provide precise positioning services.

These developments have the potential to deliver further productivity benefits to the mining, construction and agriculture sectors in particular.

3.4 Integrated guidance systems

The effectiveness of applications such as machine guidance discussed above are likely to be enhanced and extended through the integration of augmented GNSS positioning with sensors and cameras on vehicles for rapid collection of location related data. A major area of application is in the use of these integrated systems is in Unmanned Airborne Vehicles (UAVs). This has potential applications in asset management in utilities, mining, construction, surveying and even agriculture.

For example, the use of UAVs as a new technology to rapidly and repeatedly capture high volumes of asset information is currently being trialled amongst power utilities. Advances in the applications of this technology are highly dependent on supporting precision GNSS infrastructure.

In addition, with endeavours such as the NBN, there will be a renewed focus on locating underground assets as they are placed, requiring comprehensive knowledge of underground services which currently don't exist. The combined use of radio frequency identification (RFID) markers and augmented GNSS is becoming more prevalent in the industry. This technique can more accurately locate and then record underground assets.

Looking forward five years, strengthening of CORS networks (together with associated mobile signal coverage) will continue to remove the reliance on surveyors for ground control and site set-out.

Improved communications will allow automatic (on the fly) updates to be sent from the office to the site, and fewer surveyors will be able to manage more projects simultaneously. This will be an important factor in addressing the current and projected skills shortage in surveying.

It is tempting to predict that, if the improvement in precise CORS networks continues for the next five years, as it has done for the last five, that take up for machine control will be virtually universal for projects of any significant size.

In another application mentioned in the surveying report, the use of Structure from Motion software for rapid capture data on infrastructure conditions such as road and power lines. Structure from Motion uses algorithms to determine traceable points in video frames. These points are then triangulated between frames to produce a model of the road in an arbitrary 'pixel space' coordinate system. The model is then fixed to real world locations via alignment with simultaneously collected GNSS data. With the expansion of CORS networks and the use vehicle mounted cameras road condition surveys will become far more effective and efficient.

It is possible that other applications combining cameras, sensors and augmented GNSS will be extended to use in UAVs for rapid capture of asset features and infrastructure status linked to accurate location for subsequent analysis by engineers and surveyors reducing the time and resources required for field surveys.

These developments offer potential to substantially increase productivity in land and infrastructure development, road maintenance and asset maintenance and management in utilities. They have the potential to act as disruptive technologies delivering lower costs for the construction, mining, transport and utilities sectors.

3.5 Filling the gaps in augmentation

A theme that emerged in many of the reports was the availability and distribution of augmentation services as a key driver of adoption. Discontinuities in GNSS coverage can arise for a number of reasons. The most obvious arises from obstructions such as buildings, tree canopies, deep mining pits, tunnels and inside building. Discontinuities can arise from incompatibilities between different augmentation systems. Receivers set up to receive correction signals from a CORS network are not normally capable of picking up augmentation from space based augmentation systems.

A number of case studies identified this as an issue. For example it was reported as a problem for merging land based coastal surveys with bathymetric surveys in the maritime surveying report. It was also identified in the case studies undertaken for the mining sector report.

Coastal data products

The issue for coastal surveys relates to LIDAR[10] surveys (both for bathymetry and land) now being used extensively for coastal work to support the environmental modelling required for climate change and flood management. Seamless elevation data across the littoral zone is an essential requirement for the assessment of coastal risks and the development of adaptation and mitigation strategies.

Seamless coastal data products require the integration of topographic data with offshore bathymetric data. A prerequisite for the integration process is that the respective elevation data sets be related to the same vertical datum. The key

[10] LIDAR stands for Laser Detection and Ranging. It is a remote sensing technology that uses laser beams to measure distance.

linking factor between these two is augmented GNSS because it is a common vertical reference datum used in both fields.

Most coastal/port work (<30Nm) is currently using RTK or post-processing augmented GNSS, where there is infrastructure to support this work to the required accuracy. If this is not available space based differential GPS is used. There are known deficiencies related to tide gauge data density. Current research being undertaken to create a common tool to resolve these issues (Keysers, 2013).

Non satellite dependent augmentation

A technology that has potential to expand the availability of precise positioning is that of Locata[11] technology. Locata Corporation has developed a ground based radio positioning system with functionality that is equivalent to a GNSS.

A commercial application of this system has been released by Leica. The Jigsaw Positioning System (JPS) integrates a Locata signal with existing GNSS to provide a high precision positioning device for situations where GNSS signals are not available or reliable.

A potential application is in open pit mining to support machine guidance systems. A system is currently being trialled at Newmont Boddington Gold Mine (Western Australia). Early results suggest the system increases the reliability of positioning coverage in deep pit operations.

Locata technology was also tested in Sydney Harbour in October 2012 as a possible reliable location service for port operations. The tests were undertaken to assess to research how it could supplement the CORSnet in New South Wales (Harcombe, November 2012).

This development is a further step in the development of seamless precise positioning services that, if successful, have potential to extend the coverage of GNSS compatible signals to areas where GNSS signals are unable to serve as a positioning service.

Further extension of positioning services would help increase the use of augmented GNSS in a number of sectors including mining, construction, road and rail transport and logistics.

3.6 Augmented reality

Augmented reality is an emerging innovation where accurate positioning combined with digital mapping and simulation technologies is revolutionising planning and design of infrastructure.

[11] Locata is a terrestrial positioning system that could replicate GNSS. It uses a wireless synchronization technology. It provides a ground based network that replicates GNSS signals on the ground. Signals from each transmitter tower replicate at a local level, the functionality of GNSS (Lilley, August 2012)

Augmented reality (AR) combines real and virtual information in real time or near real time in a 3D environment. In the world of surveying, AR is an emerging technology that is linked to other professional areas such as town planning, mine planning, asset management, emergency management and urban renewal.

Spatial information can improve decision making in three critical respects:

- *Visualisation* – allowing patterns and trends to be illustrated in a form that can be easily understood by politicians and citizens.
- *Integration* – everything happens somewhere and the location "signature" of an event provides a mechanism for linking sources of data that cannot be easily associated using conventional approaches
- *Analysis* – the consequences of decisions degrade with distance, looking at different scenarios and the interaction of related decisions is always enhanced by considering their location criteria. For instance, selecting the site for a community facility or optimising bus routes requires spatial analysis.

Spatial information can provide the fusion of different classes of data to analyse and understand linkages between location, demographics, economic development and social services. It provides the foundation on which policy makers, planners, businesses and the community can make better strategic decisions.

With the advent of GNSS enabled mobile devices such as smart phones and tablets, AR is on the cusp of becoming a standard tool for surveying and planning professionals. AR has uses both indoor and outdoor, so whilst augmented GNSS signals such as Locata have limited use for conventional surveying, they will be critical to the take up of AR systems indoors.

For real time use, AR relies on positioning techniques, principally at present from GNSS enabled devices. Since autonomous GNSS positions in hand held devices are generally of lower precision than those from devices capable of receiving corrected signals, the uses, at present, of AR are limited to imprecise, or indicative, applications only.

If, however, autonomous positioning improves, the usefulness of AR for precise applications will correspondingly increase. For example, if a developer wishes to show a local authority the likely impact of a proposed development, the proposed building can be loaded into a tablet device, and used at the site to view the building from any location, to a precision consistent with GPS accuracy on the tablet. This is suitably accurate for this application.

However, if a local authority asset manager wishes to locate buried assets with AR enabled glasses, the GNSS positioning in the glasses needs to be of higher precision than currently available. Decimetre precision is required for the accurate location of buried services.

Therefore, for major design projects the use of augmented GNSS is likely to significantly improve the useability of AR systems. The surveying industry is yet to adopt AR as a working tool. However, the industry links with the construction and development sector where uptake is considered to be more likely and widespread. As in the machine control examples, the role of the surveyor will be in data management, quality assurance and reporting.

AR has the capacity to replace paper plans, and when linked to a single server, can provide real time updates on works in progress by combining data received from, for example, laser scanners attached to the front of construction machinery.

Full implementation of augmented reality will depend on developing the processes for sharing of geospatial data. Research is underway in the VANZI organisation to address and develop systems and protocols for the application of augmented reality systems in Australia. This technology has the potential to act as a disruptive technology for in a range of planning and development areas. It has the potential to change relationships between planners and the community for the better. It will potentially revolutionise the way in which planners, architects and engineers relate.

For the potential of augmented reality to deliver on its promise, accurate ground control is required. As discussed in the report on the surveying sector, augmented GNSS is improving the efficiency with which such controls are being established.

3.7 Agriculture

Technology diffusion rates in agriculture are slow by comparison with other industries. Farmers will adopt new technologies that offer a commercial advantage, but that has to be clearly demonstrated. If early adopters are seen by others in the industry to benefit, then diffusion can be rapid. However, the inherent variability of farming in Australia due to both climate and international market volatility can mask the evidence of commercial benefits to early adopters and impede diffusion.

As noted by Robertson et al (2010), another barrier is the perceived complexity of precision agriculture:

> "The relative difficulty of understanding and using a new system and lack of industry capacity to provide specialist technical services to growers can be a constraint to adoption…many growers find the complexity of PA technology, its demands and lack of service make it incompatible with their current farming operations".

As the industry matures, the perceptions about complexity will diminish. Grain growers have shown that as benefits are realised, adoption spreads wider. In addition, support services will become more available and at lower cost – an inevitable function of market development.

Coverage of augmented positioning is currently provided either commercially through space based or local RTK systems supplied either by Government or industry itself. In some cases farmers employ opportunistic measures such as the back cast of AMSA's DGPS[12] beacons along the coast. The extension of the CORS network will provide a more consistent availability and range of applications. This should result in increased adoption over the longer term as authoritative augmented signals become available more widely.

The rapid rise along the adoption curve of the grains industry over the last two years suggests that as other agriculture identifies the benefits of precise positioning adoption will be similarly rapid. However, the initial resistance to the technology is the fundamental barrier that needs to be overcome on an industry by industry basis.

New frontiers

One of the areas where very high precision (<2cm) has greatest potential for large productivity gains is in inter-row sowing[13]. Sowing between the rows of the previous year's grain crop minimises losses from crown rot, assists germination, enables better stubble management, minimises moisture loss and increases nutrient take-up.

In our report on the agricultural sector we reported that gains in yield of the order of 10-20 per cent are possible. This translates to a productivity gain for broad acre crop production of around 1 per cent. A recent study[14] found that farmers could "profit from inter row sowing via,

- Increased production (wheat, lentils, canola) of 0.2 to 0.4 t/ha in stubble retained systems
- Reduced costs with less stubble management ($10-25/ha)
- Increased herbicide efficacy…
- Reduced sowing problems and improved crop establishment…"

Higher precision positioning services also open up opportunities in areas such as very precise micro-irrigation (drip irrigation targeted to each plant, resulting in minimal water loss), harvest management of high value horticultural crops, and viniculture with management of individual vines.

The degree of precision will also enhance benefits already observed from positioning, such as reduced overlap in sowing, reduced overlap in coverage of agricultural chemicals (producing savings through less wastage) and very precise vehicle tracking.

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12 The Australian Maritime Authority operates a Differential GPS around Australia. DGPS is one form of augmented GNSS. For more information see Appendix A.

13 Grains Research and Development Corporation - interview

14 McCallum, Matt (2011) *Agronomic benefits of inter-row sowing with 2 cm autosteer systems*

Buick (2006) suggests that for certain crop applications precision machine operations require "pass-to-pass and repeat accuracy of =/- 1 inch (2.5cm). Such applications include strip tillage and other types of precision fertilizer placement, as well as planting and harvest of high-value crops such as potatoes, peanuts and cotton. Another critical task for +/- 1 inch accuracy is laying drip irrigation tape". These kinds of applications are not yet in use in Australia. As noted above, horticulture has been slow to realise the benefits of precision agriculture.

Greater precision also could support marketing in industries such as viticulture and wine. This is already underway in New Zealand where the location of vines is recorded for inclusion in marketing material for the specific wines.

3.8 Key Findings

The key findings of this section are that the positioning needs of those emerging applications are very similar with synergies across sectors, such as greater availability of precise positioning, better interoperability amongst current available systems including integration with other systems, such as telemetry for C-ITS and the ability of current positioning systems to deliver seamless services independent of each other.

It is also apparent that for the full benefits of these applications to be realised such as transport and automation, and any operation where safety is a high priority, integrity is critical and for some applications more important than accuracy.

An important prerequisite for further adoption and innovation in the use of augmented GNSS is the extension of GNSS services with greater compatibility between different systems. The future availability of affordable augmentations services will be an underlying driver of further adoption and innovation in its use.

Integration of augmented GNSS with other sensors, remote sensing and machine control has the potential to increase the capacity of surveyors and other spatial specialists to capture data in 3D. This will lead to faster planning, design and development of infrastructure and construction. It will also be of value to the mining and utilities sector for asset management, monitoring and maintenance.

These developments will have important applications in automated mining, machine guidance and asset management. Greater accuracy will also facilitate applications in cooperative intelligent transport systems, machine guidance and applications in agriculture.

The sectors that will be at the forefront of these developments are likely to be the mining, construction, utilities, road transport and logistics sectors. Adoption of augmented GNSS will however continue to grow in maritime activities and aviation.

The potential for these developments has been reflected in the higher estimates for economic impact in 2020. The economic benefits are substantial, through achieving existing tasks with less cost, or undertaking new tasks that in turn will improve economic efficiency.

There will also be significant social benefits, from improved safety, better use of scarce water, a reduction in polluted runoff, and reduced greenhouse and other emissions, compared with the business-as-usual scenario.

4 Global Satellite Navigation Systems (GNSS)

GNSS is a generic term that refers to constellations of satellites that provide a signal that enables users with an appropriate receiver to determine their position anywhere outdoors. The distance between a satellite and a GNSS receiver can be derived from the time it takes for the signal transmitted from the satellite to be received by the receiver. The receiver calculates the position of the devices antenna using signals from different satellites.

The principal services of relevance to Australia are the US Navstar Global Positioning System (GPS), the Russian Federation GLONASS system, and the European Union Galileo System (see Appendix A). Other countries are developing systems that will provide coverage in Australia including the Chinese Compass-Beidou System and the Japanese QZSS system.

The accuracy of the position calculated by a GNSS receiver can be degraded and made unreliable as a result of a number of interferences including:

- atmospheric effects which affects the speed of the signals
- radio-frequency interference
- multi-path effects caused by reflection of signals from surrounding buildings, terrain or trees.

Stand-alone GNSS are generally accurate to around 5 to 10 metres although errors of hundreds of metres can occur.

4.1 Augmentation services

Accuracy and reliability of GNSS positions can be enhanced by augmentation services. There are several ways in which this can occur.

One option is through differential processing of information from a fixed reference point. A base reference station is typically located in a fixed or semi-permanent location and consists of a GNSS receiver, radio and radio antenna. The base station provides a point from where the difference between the positions indicated by the satellites and the known fixed position can be calculated. This difference is then transmitted to user receivers that are equipped to correct for the errors. Differential corrections can give accuracies of around one metre.

Another option is to correct the satellite signals using real time kinematic (RTK) technologies. RTK technologies use a different approach to modelling the corrections based on the characteristics of the carrier signal from the satellite. RTK corrections can be delivered immediately to the receiver or are applied for post for applications such as surveying and mapping where immediate corrections are not required.

RTC can operate from a single base station or a network of base stations. Networks of Continuously Operating Reference Stations (CORS) have been established in Australia in some states. Accuracy is typically improved to 1 cm to 2 cm.

A third option referred to as Precise Point Positioning, calculate corrections from combining precise satellite positions and clocks with a dual-frequency GPS receiver. These corrections are generally transmitted by satellite to the user's receiver. The accuracy of these systems varies according to location. They generally provide 10 cm accuracy greater accuracies are possible in some circumstances.

Space based and ground based services

It has been common in the past to refer to different systems as space or ground based augmentation systems[15]. The whole area of GNSS augmentation services has evolved over the years it is now important to note that the augmentation category/technique should be separated from the communications media that is used to transmit the augmentation data. The terms space or ground based more appropriately refer to communication media. Basically there are two main categories of communications media – terrestrial and satellite.

Those systems that communicate the corrections from terrestrial radio beacons or by the internet for example fall into the category of ground based augmentation. Those systems that transmit correct location from satellite fall into the category of space based systems.

There are several categories of such services in Australia (see Appendix A). Ground based services include networks of government and privately owned Continuously Operating Reference Stations (CORS), DGPS beacons, operated by the Australian Maritime Safety Authority (AMSA), and a Ground Based Augmentation System (GBAS) operating at Sydney Airport. Stand-alone RTK reference stations are also installed by users for specific augmentation tasks.

There are no government owned Space Based Augmentation Systems operated by government but there are commercial systems. These include Omnistar (Trimble) and Star Fire (John Deere) and Fugro Offshore). Recently Terrapas emerged as another system that may be marketed in Australia.

4.1.2 Reliability and integrity

Reliability and integrity are important properties of GNSS positioning. Integrity refers to the time that it would take for a GNSS user to be informed

[15] Space Based Augmentation Systems (SBAS) and Ground Based Augmentation Systems (GBAS).

that the signal is corrupted. Reliability and integrity can be as important as accuracy in many applications' such as where safety is concerned.

4.1.3 Other augmentation systems

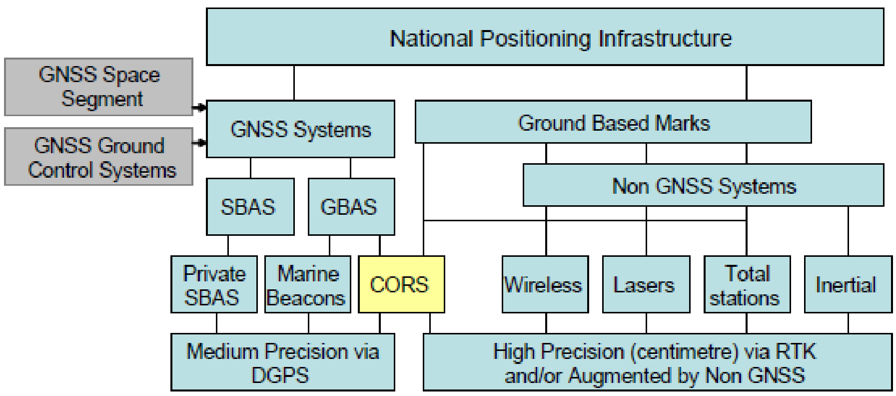
There are other augmentation systems available where GNSS does not provide sufficient integrity or availability. These include radio frequency identification, laser technologies, wireless and inertial systems. Systems that provide GNSS compatible signals from local radio transmitter beacons are also emerging applications for areas where GNSS signals cannot penetrate such as in tunnels and mines. Increasingly these technologies are being used in conjunction with GNSS augmentation systems. This is discussed further in Chapter 0 below.

4.2 National Positioning Infrastructure Policy

The purpose of the National Positioning Infrastructure Policy is to outline a set of principles for the provision of a national positioning infrastructure (NPI) that will ensure sustainable, nationally compatible deployment of GNSS Continuously Operating Reference Stations (CORS) infrastructure capable of accommodating a variety of providers and ensuring an efficient and effective Australia wide coverage and service for the positioning needs of a diverse user community.

The systems that make up national positioning infrastructure are shown in Figure 1. The CORS networks are addressed in this policy.

Figure 1 **National Positioning Infrastructure**



Data source: (ANZLIC, 2012)

Estimating the economic and social benefits of augmented GNSS is the focus of this report and by its nature will provide an estimate of the economic and social values that might arise out of the NPI.

5 Economic impacts

5.1 Overview of approach

Two approaches were taken to estimate the economic benefits of precise positioning services. For the economic impacts, a CGE modelling technique was used, drawing on studies of the impacts on specific sectors to calculate direct impacts on specific sectors and CGE modelling to calculate indirect economy wide effects.

There are four steps in the methodology:

1) Case studies of individual applications were undertaken to identify the productivity impacts in specific cases as well as the social benefits that also arise.
2) Using the case studies, desktop research and industry consultations provided evidence on which estimates of the likely level of adoption of each application across each industry sector.
3) Productivity impacts across each industry sector were estimated by scaling up the individual impacts using estimates of levels of adoption.
4) These productivity impacts were applied as sector shocks in the Tasman Global CGE model to calculate the economy wide economic impacts.

Further information on methodology is provided at Appendix B.

5.2 Productivity impacts

The net benefits derived from the individual sector reports have been converted into savings as a percentage of total output. These are summarised in Table 2.

These impacts are the improvement in productivity expressed as a percentage of output for the respective industry sector. Some benefits are spread across several sectors. For example surveying delivers benefits to the construction, mining and transport sectors.

These productivity benefits were used as inputs to ACIL Allen's Computable General Equilibrium (CGE) Model.

Table 2 **Summary of productivity impacts**

	2012	2012	2020	2020
	Low	High	Low	High
Grains	4.800%	8.000%	12.500%	21.000%
Dairy, beef			1.000%	15.000%
Mixed farming	2.000%	2.200%	2.000%	3.000%
Sugar cane (mostly)	0.100%	0.300%	0.200%	15.000%
Mining	0.603%	0.944%	1.863%	2.518%
Construction	0.431%	0.766%	0.583%	1.053%
Utilities	0.081%	0.135%	0.262%	0.411%
Road transport	0.260%	0.327%	0.989%	1.419%
Transport storage and handling	0.156%	0.182%	0.207%	0.309%
Rail transport	0.015%	0.028%	0.086%	0.084%
Aviation	0.000%	0.000%	0.030%	0.071%
Maritime	0.020%	0.050%	0.120%	0.150%

Note: 1. *Productivity is expressed as a percentage of costs.*

2. Land management and surveying productivity impacts were incorporated into the construction sector to avoid double counting.

Data source: Data from sector reports

5.3 Overview of CGE modelling approach

The productivity benefits summarised above were used as inputs to ACIL Allen's Computable General Equilibrium (CGE) model, *Tasman Global*, to estimate the impacts that spatial information induced productivity enhancements have had on the Australian economy to date as well as the potential benefits that could arise by 2020, assuming that the identified opportunities continue to be pursued by businesses and governments.

Tasman Global is a large scale, dynamic, CGE model of the world economy. A global CGE model is a powerful tool for undertaking economic analysis at the regional, state, national and global levels.

CGE models simulate the workings of the economy through a system of interdependent behavioural and accounting equations which are linked to an input-output database. These models provide a representation of the whole economy, set in a national and international trading context, using a 'bottom-up approach' – starting with individual markets, producers and consumers and building up the system via demands and production from each component. When an economic shock or disturbance such as an increase in a sector's rate of growth is applied to the model, each of the markets adjusts to a new equilibrium according to the set of behavioural parameters[16] which are underpinned by economic theory.

In addition to recognising the linkages between industries in an economy, general equilibrium models also recognise economic constraints. For example, increased demand for labour may increase real wages if there is full employment.

More detail of the *Tasman Global* model is provided in Appendix C.

5.4 Macro-economic impacts

The results for the two modelled scenarios on the Australian economy are summarised in Table 3 and Table 4. Table 3 shows the changes in a range of macroeconomic variables, while Table 4 presents a detailed breakdown of the estimated changes in Australian real GDP and real income.

To simplify interpretation, all results have been presented as changes due to the adoption of augmented GNSS technologies. Box 1 provides an overview of the main macroeconomic variables.

Box 1 Measures of macroeconomic impacts

One of the most commonly quoted macroeconomic variables at a national level is Gross Domestic Product (or GDP) which is a measure of the aggregate output generated by an economy over a period of time (typically a year). From the expenditure side, GDP is calculated by summing total private and government consumption, investment and net trade. From the income side, GDP is equal to the returns to factors of production plus all tax revenues.

Although changes in real GDP are useful measures for estimating how much the output of an economy may change, changes in the real income are more important as this provides an indication of the change in economic welfare of the citizens. Indeed, it is possible that real GDP can increase with no, or possibly negative, changes in real income. In the Tasman Global model, changes in real income at the national level is synonymous with real gross national disposable income (RGNDI) reported by the ABS.

Real income is equivalent to real GDP plus net foreign income transfers, while the change in real income is equivalent to the change in real economic output, plus the change in net foreign income transfers, plus the change in terms of trade (which measures changes in the purchasing power of a region's exports relative to its imports). As the residents of many countries have experienced in recent years, changes in terms of trade can have a substantial impact on people's welfare independently of changes in real GDP.

Source: ACIL Allen Consulting

16 An example of a behavioural parameter is the *price elasticity of demand* – the responsiveness of demand for a commodity to a change in the price of that commodity. Each of these markets, for example the market for a commodity or a factor such as labour or land or the market for capital goods, is then linked through trade and investment flows.

Table 3 **Australian macroeconomic impacts of adoption of augmented GNSS technologies**

	Units	Accumulated impacts as at 2012		Projected impacts	
		LOW Case	HIGH Case	LOW Case	HIGH Case
		2012	2012	2020	2020
Real GDP					
Real GDP	2012 A$m	2,288	3,717	7,832	13,715
	%	0.16	0.25	0.43	0.74
Real income	2012 A$m	1,633	2,670	5,373	10,115
	%	0.11	0.18	0.28	0.54
Real private consumption	2012 A$m	560	853	2,630	5,904
	%	0.07	0.11	0.26	0.62
Real investment	2012 A$m	623	1,010	2,111	3,717
	%	0.19	0.31	0.53	0.91
Real exports	2012 A$m	1,211	1,986	3,884	5,833
	%	0.27	0.44	0.74	1.13
Real imports	2012 A$m	240	344	1,229	2,560
	%	0.05	0.07	0.20	0.42
Net real foreign trade	2012 A$m	971	1,641	2,655	3,273
Real wages	%	0.06	0.09	0.24	0.62

Data source: Tasman Global modelling estimates

Table 4 **Decomposition of changes in Australian real GSP and real income (2012 A$m)**

	Quantifiable historical productivity scenario		Projected	
	LOW Case	HIGH Case	LOW Case	HIGH Case
	2012	2012	2020	2020
Change in value added	254.6	402.1	1,590.9	3,075.0
Change in tax revenues	304.6	479.8	1,314.7	2,491.1
Productivity effects	1,729.0	2,834.6	4,926.3	8,148.9
Total change in real GDP (income side)	**2,288.2**	**3,716.5**	**7,831.9**	**13,715.1**
Change in terms of trade	-681.1	-1,094.5	-2,484.4	-3,608.7
Change in net foreign income transfers	25.8	48.2	25.3	8.6
Total change in real income	**1,632.9**	**2,670.2**	**5,372.8**	**10,114.9**

Data source: Tasman Global modelling estimates

5.4.1 Impacts of augmented GNSS in 2012

Real GDP

Based on our low case estimate, Tasman Global modelling estimates that, by 2012, Australia's real GDP was **$2.29 billion higher** than it would have otherwise been without the productivity improvements arising from augmented GNSS.

With less conservative estimates, this contribution could have been as high as **$3.72 billion** by 2012. Our less conservative estimate is based on our understanding of levels of adoption from industry consultations.

These estimates represent increases **in GDP 0.16 per cent and 0.25 per cent** respectively.

These results can be analysed in more depth by decomposing the changes in value added, tax revenues and productivity effects (i.e. changes in income side of GDP). As shown in Table 4.

- Productivity improvements account for approximately 76 per cent of the increase in real GDP.
- Approximately 13 per cent of the increase is associated with increased net tax revenues due to resulting increased economic activity.
- Approximately 11 per cent of the increase in real GDP is due to increased real returns to labour, capital and resources which results from the higher resources availability, higher accumulated capital stocks and allocative efficiency benefits associated with the reallocation of resources in the economy.

This underlines the importance of technologies and services enabled by augmented GNSS to economic growth.

Real income

Although changes in real GDP is a useful measure for estimating how much the output of the Australian economy has changed, changes in the real income are more important to economic welfare. In *Tasman Global,* changes in real welfare is measured by real income[17] and, at a national level, is synonymous with real gross national disposable income (RGNDI) reported by the ABS.

Real income in 2012 is estimated to have increased by between **$1.63 billion and $2.67 billion,** as a direct result of the quantifiable productivity improvements generated from the use of modern augmented GNSS technologies (see Table 3). This represents an increase of 0.11 per cent to 0.18 per cent of real income.

The productivity improvements associated with the adoption of augmented GNSS have reduced production costs and boosted total production. Most of these cost reductions are passed on to final consumers in Australia and overseas.

[17] More specifically, in *Tasman Global*, changes in real GNP are equivalent to changes in equivalent variation (using the Slutsky measure of income effects). See Pant (2007) for more details.

Other macroeconomic variables

An important result is that the productivity improvements are estimated to have increased real exports by between **$1.21 billion and $1.99 billion** by 2012. The increased exports would have enabled Australians to purchase more foreign goods and services (largely manufactured goods such as cars, electronic goods and clothing). Real imports by comparison estimated to have been only marginally affected.

In aggregate, net foreign trade (exports minus imports) is estimated to have been improved in real terms by between **$0.97 billion and $1.64 billion by 2012**.

5.4.2 Impacts of augmented GNSS in 2020

The modelling results show that the greater adoption of augmented GNSS technologies that require augmented GNSS would lead to further economic and welfare gains for Australia.

Due to the larger productivity gains under the two 'future adoption' scenarios, the overall economic impacts under this scenario are larger in 2020. The additional GDP attributable to use and adoption of augmented GNSS by 2020 is estimated to be:

- **$7.83 billion**, under the Low Case (in real 2012 terms) or an additional **$5.54 billion** over that estimated for 2012.
- **$13.90 billion**, under High Case (in real 2012 terms).or an additional **$10.00 billion** over that estimated for 2012

Real income also increases further by 2020. The additional real income attributable to the use and adoption of augmented GNSS is estimated to be:

- **$5.37 billion**, under Low Case(in real 2012 terms) or an additional **$3.74 billion** over 2012
- **$10.12 billion**, under High Case (in real 2012 terms) or an additional **$7.44 billion** over that estimated for 2012

The trade impacts by 2020 are projected to be

- Exports higher by between **$3.88 billion** and **$5.83 billion**
- Imports lower by between **$1.23billion** and **$2.56 billion**

5.4.3 Other impacts

Real household consumption is estimated to be higher under the Low and High Cases by

- between 0.07 per cent and 0.11 per cent respectively in 2012
- between 0.26 per cent and 0.62 per cent respectively by 2020.

Real investment is estimated to be higher under the Low and High Cases by

- between 0.0.19 per cent and 0.31 per cent respectively in 2012

- between 0.53 per cent and 0.91 per cent respectively by 2020.

Real wages estimated to be higher under the Low and High Cases by:

- between 0.06 per cent and 0.09 per cent higher respectively in 2012
- between 0.24 per cent and 0.62 per cent higher respectively by 2020.

5.4.4 Sector impacts

The impacts on selected sectors are shown in Table 5.

Table 5 **Increases in sector outputs**

	Low case	High case	Low case	High case	Low case	High case	Low case	High case
	2012	**2012**	**2020**	**2020**	**2012**	**2012**	**2020**	**2020**
	$ million	**$ million**	**$ million**	**$ million**	**%**	**%**	**%**	**%**
Grains	279	434	773	1,377	1.9	2.9	7.6	13.8
Dairy, beef	18	29	105	791	0.1	0.2	0.4	3.3
Other crops including sugar cane	1	2	6	17	0.1	0.2	0.4	1.1
Mining	682	1,084	2,437	3,134	0.4	0.7	1.1	1.4
Construction	440	711	1,401	2,469	0.1	0.2	0.3	0.5
Utilities	50	81	173	305	0.1	0.2	0.3	0.5
Road transport	96	137	442	752	0.2	0.3	0.6	1.1
Transport storage and handling	58	76	93	164	0.1	0.1	0.1	0.2
Rail transport	1	3	10	12	0.0	0.0	0.1	0.1
Aviation	10	18	48	66	0.0	0.1	0.2	0.2
Maritime	9	16	41	60	0.1	0.2	0.4	0.6

Note☹1) Surveying is included in the construction and mining sectors.
Data source: *ACiL Allan*

The table shows the growth in output for each industry sector and the percentage growth. The largest impacts in 2012 were in the grains, construction and mining sectors. Increase in output in road transport, storage and handling and surveying and land management was also significant. These results reflect both the level of use of augmented GNSS based services as well as the relative size of those sectors.

The higher numbers in 2020 reflect the assumed high level of adoption of machine guidance and automated mining and construction sectors. It also assumed close to 100 per cent in advanced surveying, cooperative intelligent transport systems and the grains and livestock industries. The high case assumes considerable innovation in applications, some of which are currently speculative but could eventuate.

The higher outcomes in 2020 also assume that GNSS augmentation services will continue to expand. The high case assumes that CORS networks are expanded with metropolitan and regional coverage in all States and Territories.

The difference between the high and the low cases is primarily attributable to different assumptions of the level of adoption. Increased adoption will be driven strongly by the availability of competitive augmentation services. The rate of expansion of CORS networks will be an important factor. In addition, greater compatibility between systems and development of GNSS receivers that can access more than one system will also be important.

6 Social impacts

There are many social and environmental benefits from augmented GNSS services.

They play an important role in supporting safer working environments. Automated or remotely operated machine guidance removes operators from dangerous situations and from exposure to dust and contaminants such as in the mining and construction sectors. The use of augmentation systems in the aviation and maritime sector contributes to safer navigation. This is important for safety of life at sea and in the air. It has potential to increase road safety in the future though its use in cooperative intelligent transport systems.

Augmented GNSS also has a role to play in preserving environmental and cultural values. It has been used by gas producers for mapping sites of cultural value when planning pipeline routes. It is also being used to more precisely measure tidal movements and sea level rise. Expansion of augmented GNSS services is expected to increase its use in these activities.

There are other important benefits for the community. An improved capacity to monitor sea level rise helps development of adaptation policies and future planning for coastal communities. Its use in support of augmented reality technologies in future planning and design will assist the community to better understand the social and environmental impacts of developments.

Impacts of development activities on communities are reduced through faster execution of construction projects and better route planning for roads. Faster repairs and maintenance of utilities infrastructure reduces the disruption of access to footpaths and roads, and reduces interruptions to suppliers of utility services.

Improved mapping of the coastal region and linking land and bathymetric surveying will provide more accurate maps for planners in developing policies and actions to address both the impact of sea level rise as well as better managing the impact of land use and runoff on the marine environment. Expansion or the CORS[18] network for example could assist in more accurate monitoring of sea level change from tide gauges.

The use of augmented GNSS in intelligent transport systems will help reduce fuel consumption and emissions of greenhouse gases in road transport. It is also helping reduce fuel consumption in aviation through enabling user preferred routes and in more efficient airport approaches and landings.

Precision agriculture techniques allow more effective use of water on farms. This has economic value for farm production as well as for the environment.

18 Continuously Operating Reference Stations and a form of augmented GNSS. For more information see Appendix A

Augmented GNSS has applications in some aerial mapping operations that provide the base mapping data used in natural resources management.

Precise positioning technologies allow more efficient application of fertilisers, in turn reducing chemical run-off. Likewise it can help minimise the impact on the environment of mining operations through better management of materials handling and more accurate monitoring of potential hazards such as leachates from tailings dams. Augmentation systems in the maritime sector improve navigation and reduce the risk of oil spills. A serious oil spill in the Great Barrier Marine Park for example, would not only damage reef ecology, it would also affect fishing and tourism.

Improved efficiency through use of positioning technology in the agriculture, mining, survey and land development, construction, utilities, and transport sectors, reduces costs and has the potential to reduce prices to consumers. While these impacts are more broadly captured in the economic results they are nevertheless important benefits to society in general.

7 Conclusions

This report has found that augmented GNSS services have delivered significant economic benefits to Australian industries and social and environmental benefits to society. This is being realised through its direct use and through its support of other systems.

Analysis of its impacts in 9 sectors of the Australian economy showed that in 2012, GDP was between $2.29 million and $3.72 million higher as a result of the use of augmented GNSS services. These amounts represent increases of 0.16 per cent and 0.25 per cent respectively.

Augmented GNSS is an enabling technology that when combined with geographic information systems, remote sensing, intelligent transport systems, vehicle mounted cameras and machine guidance systems, has considerable potential to deliver productivity improvements in many sectors of the economy.

With further expansion of augmented GNSS services and their integration with other systems the contribution to GDP could increase further to between $7.83 million and $13.72 million compared with the alternative without augmented GNSS. These projections assume high levels of adoption and expansion of augmented GNSS based services.

The high case in 2020 assumes almost 100 per cent adoption in areas such as grains and surveying and high levels of use in other sectors. Some of the applications assumed in the 2020 high case are under research at the present time and should be considered as speculative.

The projected results for 2020 will depend on an increased pace of adoption in all sectors. This is not unreasonable as many industries are at the early stages of adoption. As the systems become more widespread, the demonstration effect will most likely help drive further adoption. The future outcomes modelled also assume expansion of augmented GNSS services and greater compatibility between services

Sectors

The greatest economic impact from the use of augmented GNSS is in the agricultural, mining, construction and surveying sectors. The utilities and transport sectors have also realised important economic benefits through improved asset management and logistics.

The use of augmented GNSS by the grains industry has enabled controlled traffic farming, yield monitoring and variable rate fertiliser applications. The benefits have been shown in the high increase in sector output for the grains industry shown in in Table 5 in Chapter 5.

Future applications are likely to extend into new areas such as managing and monitoring cattle and potentially for marketing purposes such as in tracing the source of grapes in the wine industry.

The mining and construction sectors have realised considerable economic efficiencies from the use of augmented GNSS in site surveying, machine guidance and asset management. Examples include workforce savings ranging from between 20 per cent and 40 per cent for mine site and construction surveying and between 10 per cent and 20 per cent in the use of machine guidance and autonomous haul trucks. Higher estimates have been reported at some mines. Automated mining is reported to deliver overall productivity gains of up to 15 per cent. The cost of down time for seismic vessels is reported to be reduced by around 10 per cent as a result of the use of precise positioning.

Surveying has been at the forefront of the application of precise positioning technologies. An important development in surveying is the combination of augmented GNSS, sensors and cameras mounted on vehicles for rapid capture of location referenced features.

The road transport and logistics sector has benefited from the use and application of augmented GNSS. It has reduced fuel consumption in transport logistics and fleet management by around 10 per cent. It has demonstrated cost savings for container management at some ports of around 30 per cent.

The utilities sector (electricity, gas, water and waste water) use augmented GNSS for asset mapping. Cost savings of up to 10 per cent have been achieved.

GNSS has become integral to navigation in aviation and maritime sectors and augmented GNSS is being increasingly developed as a navigation support tool. There are some operational benefits from augmented GNSS in the form of lower fuel and operating costs but they are not as significant as in some of the other sectors or compared to the benefits of improved safety and reduced risk and cost of accidents.

The economic benefits from the use of augmented GNSS in the rail sector are mainly derived from cost savings in surveying track, signals and transponders. There is potential for the use of augmented GNSS in Automated Train Management Systems, largely replacing traditional signals – with productivity and safety benefits. This is mainly in the long haul and resources sector as the metropolitan networks use systems that are based on track transponders.

Environmental and Social impacts

Augmented GNSS has delivered important social and environmental benefits. Augmented GNSS assists better water management on farms and in mines where higher accuracy in mapping and control systems assist managers in increasing water use efficiency and in managing the impact on water resources more effectively.

Through more efficient asset mapping and better management of construction it reduces the impact on the community of maintenance and construction activities.

It assists the mining sector with more accurate environmental monitoring and better materials handling to reduce the environmental footprint. It also supports locating cultural heritage sites for planning purposes.

Improved route planning and cooperative intelligent transport systems in the road transport sector will help reduce traffic congestion, lower fuel consumption and emissions, and reduce the level of interruption to motorists during maintenance periods. Lower costs for surveying and route planning will also assist in minimising the impact on the environment of future developments.

An important role for augmented GNSS is in helping to minimise the risk of maritime accidents. This is particularly important in relation to reducing the risk of oil spills and protection areas of high environmental value including the Great Barrier Reef Marine Park.

Future location based applications

The emergence of Cooperative Intelligent Transport Systems (C-ITS) is expected to find further application of augmented GNSS systems in managing traffic movements and linking road users to the road environment through real time sharing of information on vehicle and infrastructure status, road traffic conditions and potential hazards. Knowledge of accurate vehicle location is required for many potential C-ITS applications and in particular for safety-of-life applications.

The use of machine guidance supported by augmented GNSS in both the mining and the construction sectors has significant potential for further economic benefit. Automated mining is seen by industry leaders as a critical to maintaining competitiveness in global markets.

Development of ground based radio positioning systems that offer the potential to deliver localised GNSS in deep pits, underground and in tunnels will be important for the wider use of augmented GNSS in the construction mining and transport sectors.

An important potential development is the use of augmented GNSS with vehicle mounted cameras and remote sensing for rapid acquisition of location related data. The use of Unmanned Aerial Vehicles (UAV) as a new technology to rapidly and repeatedly capture high volumes of asset information is currently being trialled by some power utilities.

Future developments in the application of augmented reality offer potential for improved community consultation at the planning stage of major infrastructure developments. This has important implications for the interaction between the community, planners, architects and engineers in planning new developments.

Augmented GNSS can improve the way industries operate and provide new approaches operations and asset management. Those who think ahead of the pack will do well from finding further advances made possible by the use of augmented GNSS.

Appendix A Augmented GNSS

A.1 Introduction

Global Navigational Satellite Systems (GNSS) have become a part of everyday life for many Australians. The range of applications is growing rapidly from in car navigation, self-steering tractors to ATMs. The signal from positioning satellites is becoming part of an underlying infrastructure of location and time information. In a growing interconnected world, society's reliance in high integrity positional, navigational and timing (PNT) data is growing.

The first Global Positioning System (GPS) was initially developed by the US military as a military system but was later extended to "dual-use" for both military and civilian applications. Other systems have also been developed and Australians will soon have a number of alternative systems that can be used to provide and augment existing positioning services.

The GPS service for a stand-alone receiver provides accuracy at the metre level. However it can be subject to many errors such as those caused by atmospheric variations, multipath and periodic errors (due to the visibility and geometry of satellite constellation). Higher accuracy and integrity can be provided through the provision of corrections via a master control system or from a network of fixed reference ground stations to augment system accuracy.

The technology for positioning is evolving rapidly, with an increasing number of satellite services becoming available. Importantly Australia will be one of the few countries in the world with the ability to receive signals from the existing and emerging satellite navigation systems.

A.2 Existing and emerging GNSS

The principal services of relevance to Australia are summarised in Table 5.

Table 6 **GNNS satellite systems**

Service	Country	Operational status	Services provided	Accuracy
Global Positioning System (GPS)	United States of America	Operational – constellation of 24 satellites plus 1 master control station and 5 monitor stations.	Basic service is free to the user. Wide area augmentation not available in Australia.	3 m horizontal 5 m vertical 95 per cent of the time
GLONASS	Russian Federation	Operational – 24 satellites globally.	Standard service free High access only for special applications	6 m horizontal 95 per cent of the time.
Galileo	European Union	In testing phase. Fully operational by 2020	Open service free	4 to 15 m horizontal depending on number of frequency bands used.
Compass/ Beidou	China	Globally operational	Open service free Augmented services will be charged.	5 m horizontal
Quasi-Zenith Satellite System	Japan	Operational in Japan but under test for Australia.	An augmentation service for GPS. Comprises a conventional and augmentation service.	1 m for augmentation service

Note: This list is not exclusive. The services represented in this table are those that are or are likely to be available to users in Australia.
Data source: *(UN Office for Outer Space Affairs, 2010)*

A.2.1 US GPS

The US GPS constellation of satellites is the most common service used around the world today. The US Navstar satellites were first launched in 1978 and became available for civilian use in 1983. In 2000 the US turned off "selective availability", an intentionally introduced error. The US is now updating the GPS system with GPS III satellites designed to provide new signals and greater capabilities.

GPS encompasses three segments—space, control, and user. The space segment includes the 24 operational satellites that orbit the earth every 12 hours at an altitude of approximately 20,200 kilometres. Each satellite contains several high-precision atomic clocks and constantly transmits radio signals using a unique identifying code.

One master control station, five monitor stations, and ground antennas comprise the control segment. The monitor stations track each satellite continuously and provide data to a master control station. The master control station calculates changes in each satellite's position and timing that are in turn forwarded to the ground antennas and transmitted to each satellite daily.

GPS receivers process the signals transmitted by the satellites. Provided at least three satellites are in view at any one time, the receivers can triangulate their position giving in the horizontal plane as well as in the vertical plane. With raw

GPS position is generally more accurate in the horizontal plane than in the vertical plane.

At the present time uses of stand-alone GPS can generally expect horizontal accuracy of 3 metres or better and vertical accuracy of 5 metres 95 per cent of the time.

A.2.2 GLONASS

GLONASS is operated by the Russian Space Agency ROSCOSMOS and after a few false starts reached its full operational status in November 2011, with 24 active satellites. GLONASS will also undergo a modernisation plan in the coming years. The future GLONASS-K2 satellites, commencing operation in 2013, will transmit 3 carrier frequencies using CDMA[19].

Figure A1 **GLONASS constellation of satellites**

Data source: http://www.glonass-ianc.rsa.ru/ accessed on 20 September 2012

GLONASS satellites broadcast two signals of differing accuracy. The standard positioning signal is available to all users for no charge whereas the high accuracy positioning signal is subject to an access code and is used for special applications.

The range error over for the open system is estimated to be less than or equal to around 6 metres with 95 per cent probability.

A.2.3 Galileo

Galileo is being developed by the European Space Agency (ESA) and will be the European Union's GNSS. Galileo will be under civilian control but will be

19 CDMA (Code Division Multiple Access) is a method for transmitting multiple digital signals simultaneously over the same carrier frequency

consistent with GPS and GLONASS. It will deliver real-time positioning accuracy down to the metre range with a high level of service availability. It will inform users within seconds of satellite failure, making it suitable for safety-critical applications such as guiding cars, running trains and landing aircraft.

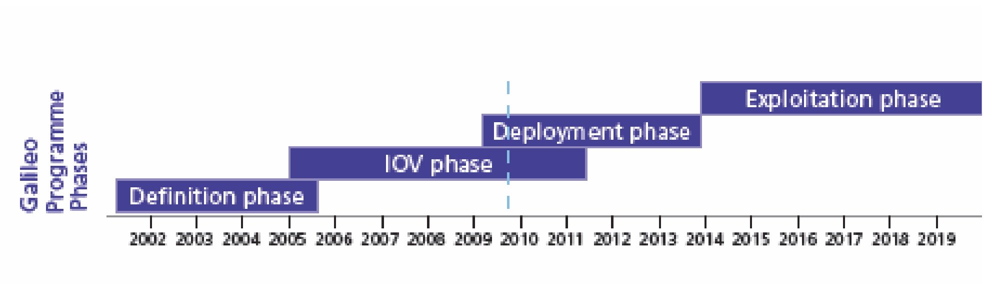
ESA's first two navigation satellites, GIOVE-A and –B, were launched in 2005 and 2008 respectively. The first two of four operational satellites designed to validate the Galileo concept in both space and on Earth were launched in 2011. Two further satellites are scheduled to be launched in October 2012. Once the validation phase has been completed, additional satellites will be launched to reach Initial Operational Capability (IOC) around mid-decade.

The fully deployed GALILEO system will consists of 30 satellites, positioned in three circular Medium Earth Orbit planes at 23 222 km altitude above the Earth, and at an inclination of the orbital planes of 56 degrees to the equator.

GALILEO will provide a number of services. The Open Service will be available free of charge. It will provide horizontal accuracy of between 4 metres and 15 metres depending on whether a dual frequency or single frequency receiver is employed. The confidence level for positioning and timing will be 95 per cent.

The system is to be fully operational by around 2020. The timetable for deployment is illustrated in Figure A2.

Figure A2 **Timetable for deployment of the GALILEO system**



Data source: (UN Office for Outer Space Affairs, 2010)

A.2.4 Compass/Beidou

China is building its own GNSS referred to as Compass/Beidou. The system is in the early- to mid- development stage. Implementation of the system is expected to continue until 2020 when it is expected to comprise 5 geostationary satellites and 30 non-geostationary satellites.

China plans to complete Phase 2 of the development during 2012, when it will cover China and surrounding regions. At the end of Stage 2, the constellation will consist of 5 satellites in Geostationary Orbit (GEO), another 5 satellites in Inclined Geosynchronous Orbit (IGSO) and 4 satellites in Medium Earth Orbits (MEO). Phase 3, which will commence with further satellite launches later in 2012, will involve and transition from regional coverage to a global

GNSS with the constellation reaching 5 GEOs, 3 IGSOs and 27 MEOs in the 2018 to 2020 timeframe.

Like GPS, GLONASS and Galileo, Compass/Beidou will have an open service and an authorised service. The open service will be free and has a positioning accuracy of 10 metres at 95 per cent reliability.

A.2.5 Indian Regional Navigation Satellite System (IRNSS)

India is developing the Indian Regional Navigation Satellite System (IRNSS). A constellation of three geostationary and four orbiting satellites, India expects the IRNSS to be completed in 2014.

The system will have a standard service and a restricted service. While there is little information in the public domain regarding longer term plans it has been assumed by most industry observers that the IRNSS would primarily provide services to areas covering India. Accuracy of the standard services is reported to be better than 10 metres over India.

A.2.6 The Quasi-Zenith Satellite System

Japan is developing a regional navigation satellite system, the Quasi-Zenith Satellite System (QZSS).

The first stage is planned to include three satellites, broadcasting signals very similar to GPS, which will orbit in a figure eight pattern over Japan and the East Asian region south to Australia. The orbit is designed to ensure that the satellites will be at a high elevation angle over Japan, allowing extra positioning signals to be available in the urban canyons of Japanese cities. The first of the QZSS satellites was successfully launched in September 2010.

In addition to conventional GNSS signals, the QZSS satellites will also transmit an augmentation signal called LEX (L-band Experimental Signal). The conventional service has been tested to deliver position accuracy of 7.02 metres (95 per cent of the time) with a single frequency receiver and 6.11 metres (95 per cent of the time) with a dual frequency receiver.

The augmentation service is expected to provide positional accuracy of 1 metre.

A.3 Augmentation systems

While stand-alone GNSS signals are suitable for many existing applications such as in car navigation, general map directions and social networking, they are not suitable for applications where more accurate positioning, high reliability and/or precise timing are required. Stand-alone signals are accurate to around 5 to 10 metres however in some cases errors can exceed this by well in excess of 100 metres.

Errors can arise from a number of factors:

- Satellite orbits
- Atmospheric interference (ionosphere and troposphere)
- Radio-frequency interference
- False signals reflected from surrounding buildings, terrain or flora
- Satellite and receiver clock errors
- Intentional jamming.

More accurate positioning can be provided in a number of ways including through non-land based reference systems such as inertial systems and receiver autonomous integrity monitoring (RAIMS). However, augmentation generally involves augmenting stand-alone GNSS by modelling errors locally and transmitting these errors to a user's receiver so that the error can be corrected in the user's receiver.

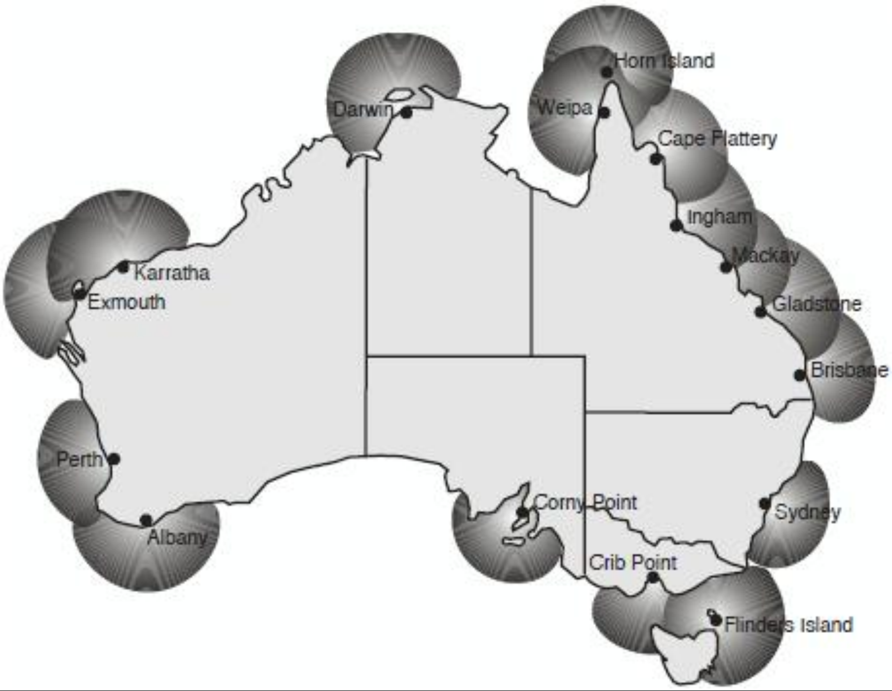
The technology is evolving rapidly and the method of modelling the errors and transmitting the correction to the user's receiver vary between systems.

A.3.1 Differential GPS (DGPS)

DGPS uses differential processing of information from a fixed reference point. A base reference station is typically located in a fixed or semi-permanent location and consists of a GNSS receiver, radio and radio antenna. The base station provides a point from where the difference between the positions indicated by the satellites and the known fixed position can be calculated. This difference is then transmitted to user receivers that are equipped to correct for the errors. Differential corrections can give accuracies of around one metre.

DGPS corrections are most commonly transmitted by radio beacon. There are a number of such applications in Australia. One example is the service operated by AMSA around the Australian coast to around 150 nautical miles.

Figure A3 **Coverage of the AMSA DGPS service**



Source: AMSA.

A.3.2 Real time kinematics (RTK)

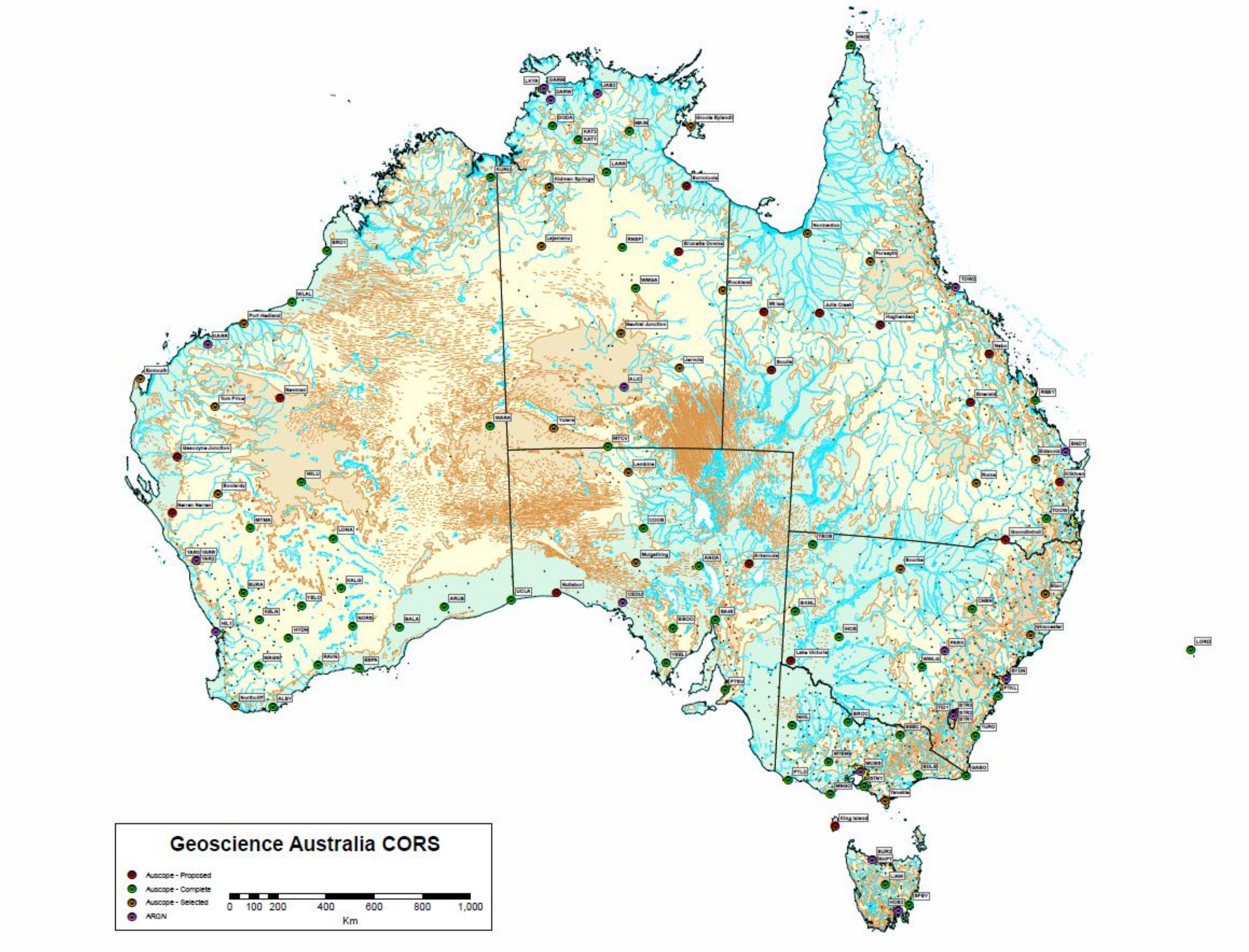
RTK technologies use a different approach to modelling the corrections based on the characteristics of the carrier signal from the satellite.

RTK corrections can be delivered immediately to the receiver (Real Time Kinematic refers strictly to real time) or are applied for post for applications such as surveying and mapping where immediate corrections are not required.

Stand-alone RTK services are already being provided by private companies to service specific regions mainly for agriculture enterprises, mining and state and local government. Accurate wide areas RTK corrections can be provided using networks of base stations.

An initial investment in a CORS network across Australia commenced under the AUSCOPE component of the National Research Infrastructure Strategy. The initial investment was undertaken by Geoscience Australia in collaboration with the Australian National University, the University of Tasmania and Curtin University and was established for scientific purposes.

Figure A4 **The AusCope CORS network**



Data source: if outside data used and we have charted it

Some State Governments have invested in CORS networks that in some cases draw on the AuScope network to density their services. Examples include

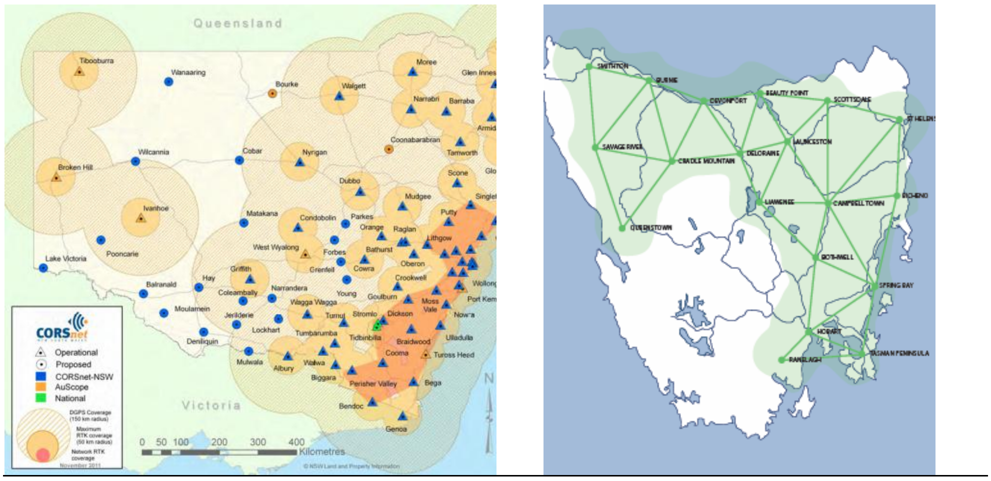
- GPSnet (Victoria),
- CORSnet NSW
- SunPOZ (Queensland).

The private sector has also invested in CORS networks such as

- SMARTNet, (CR Kennedy)
- AllDayRTK, (Position Partners)
- GNSS Network Perth (Timble)
- Checkpoint (GlobalCors)
- Omnistar CORS network (Ultimate Technologies and Omistar)

The Government owned CORSnet NSW and the privately owned Omnistar CORS network in Tasmania are shown in Figure A5.

Figure A5 **CORS networks in New South Wales and Tasmania**



Data source: if outside data used and we have charted it

Specific purpose reference stations have also been developed for agriculture applications. These include

- Trimble owned Omnistar Operations
- Starfire operated by John Deere

The number of stand-alone reference stations in Australia was estimated to be around 3000 in 2008 and the demand for services is understood to be growing rapidly (Lateral Economics, January 2009).

A.3.3 Precise Point Positioning (PPP)

PPP systems do not rely on reference stations in the user's area of operation. Instead they calculate corrections by combining precise satellite positions and clocks with dual-frequency GPS receivers. They utilise regional reference stations. These corrections are generally transmitted by satellite to the user's receiver. The accuracy of these systems varies according to location but ranges from 10 cm to 1 cm in certain locations.

There are no government systems in Australia but there are commercial systems operating. These include Omnistar (Trimble) and (Star Fire) John Deere and Fugro (Offshore). Recently Terrapas emerged as another system that may be marketed in Australia.

The accuracy of the commercial systems currently operating in Australia is of the order of decimetres but can be up to centimetre accuracy. The system can require up to twenty minutes to calculate the error. The commercial operations in Australia have mainly been in the agriculture and petroleum areas.

A.3.4 Non satellite dependent positioning systems

There are a number of non-satellite dependent positioning systems available where GNSS does not provide sufficient integrity or availability. These include radio frequency identification, laser technologies, wireless and inertial systems.

One system developed in Australia (Locata) can provide GPS type signals for areas where GNSS cannot penetrate. Such applications are being applied in mines and tunnels and can operate seamlessly with GNSS systems.

Appendix B Methodology

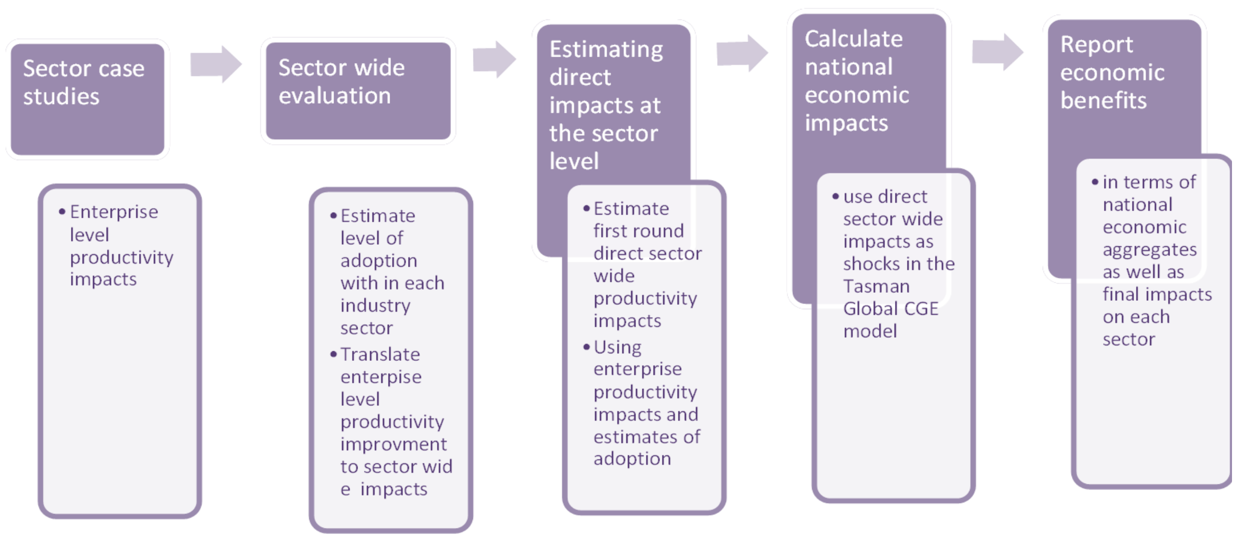
Two approaches were taken to estimate the economic and social benefits of precise positioning services. For the economic impacts, a CGE modelling technique was adopted drawing on studies of the impacts on specific sectors to calculate both the direct impact on identified sectors and the indirect effects using the Tasman Global CGE model. For the social and environmental benefits, a mix of quantitative and qualitative assessments drawing on published studies and estimates to provide additional assessments largely in a qualitative manner.

There are four steps in the methodology:

5) Case studies of individual applications were undertaken to identify the productivity impacts in specific cases as well as the social benefits that also arise.
6) Using the case studies, desktop research and industry consultations provided evidence on which estimates of the likely level of adoption of each application across each industry sector.
7) Productivity impacts across each industry sector were estimated by scaling up the individual impacts using levels of adoption.
8) These productivity impacts were applied as sector shocks in the Tasman Global CGE model to calculate the economy wide economic impacts.

The approach is summarised in Figure 6.

Figure 6 **Benefits estimation sequence**



Source: ACIL Allen

B.1 Estimating productivity impacts

B.1.1 Drivers of benefits

There are two drivers of net economic benefit from augmented GNSS when used in economic applications.

Productivity improvement

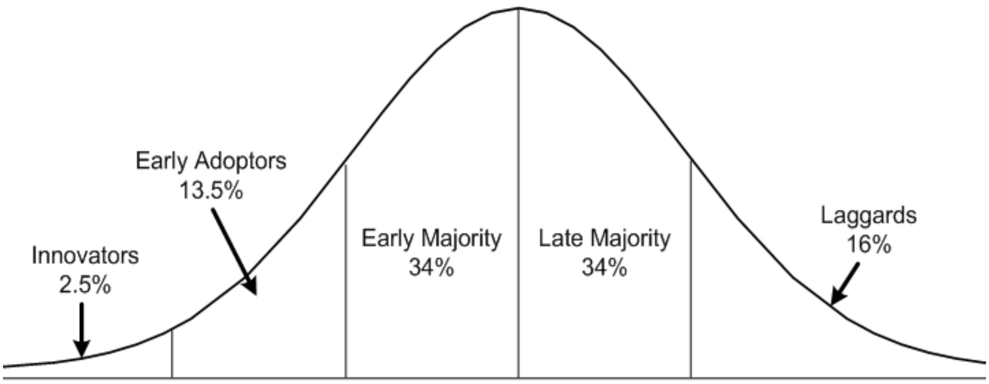
The first is the basic productivity improvement that arises from the application of new technology or new techniques that are made possible from the application of precise positioning. Some of these are mentioned later in this overview report.

Productivity improvement is at its core increasing the level of output per level of input. Productivity improvements can be in the form of doing the same with less resources or producing more with the same resources.

Adoption

The case studies, industry consultations and desktop studies provided estimates of adoption of these technologies across each industry sector. These estimates were be made for 2012 and for 2017 (along the lines of an adoption model shown in Figure 7.

Figure 7 **Roger's model of adoption**

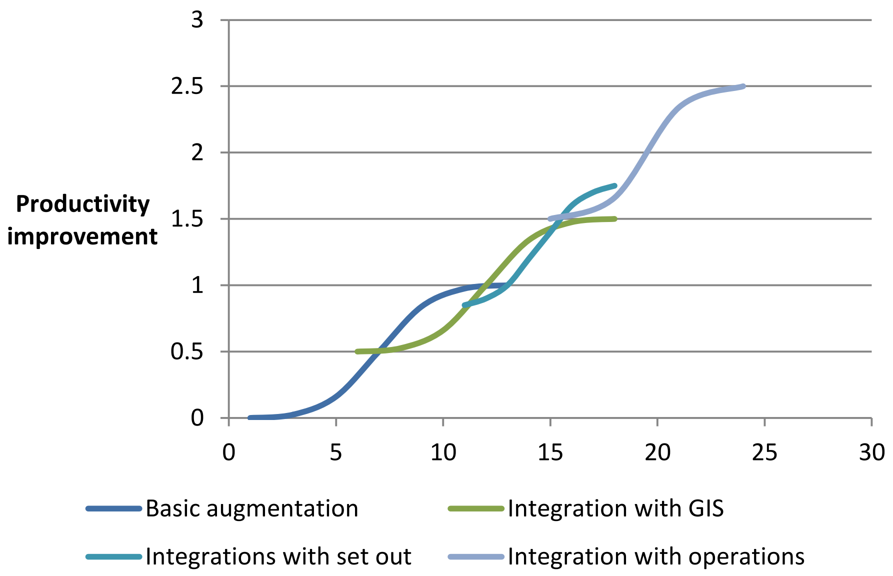


Data source: Rogers (1964)

This approach to adoption results in an S- shaped curve for the delivery of benefits. The benefits appear slowly at first and then accelerate as adoption moves from majority adopters to late majority adopters.

The issue with assuming a simplistic S-shape uptake curve is, however, that the geospatial market as a whole is dynamic over time and that there are in fact many different types of spatially enabled products and services. With many related technologies it was found that augmented GNSS and related spatial technologies lead to waves of adoption curves. In each case the productivity improvements build on the previous wave of technology as shown in Figure 8.

Figure 8 **Indicative waves of innovation with augmented GNSS**



Note: levels of productivity are for illustrative purposes only.

Data source: (ConsultingWhere and ACIL Tasman, 2010)

The combined effect of productivity improvements in specific applications combined with levels of adoption provide the estimate of overall productivity impacts for each sector.

B.1.2 Framework

Precise positioning through augmented GNSS is an enabling technology that when applied with other spatial and control technologies can improve the efficiency of other activities such as mining or construction. It is important therefore to be able to capture the wider industry impacts of its use.

To do this we adopted a reference case and a counterfactual:

- The reference case reflected the current and future potential uses of augmented GNSS by the sectors examined.
- The counterfactual on the other hand represented a hypothetical situation where this augmented GNSS were not available.

The counterfactual does not mean that nothing would happen to deliver more accurate or reliable position information. There are other approaches to obtaining precise position in most cases. However they are generally less effective, more expensive or may produce less comprehensive results. These alternative approaches need to be taken into account when considering the counterfactual.

Augmented GNSS first appeared around the early 1990s when it was introduced to address selective availability in GPS signals[20]. However, the value of correction signals became apparent more widely and augmented GNSS systems were further developed to meet growing demands for more accurate positioning.

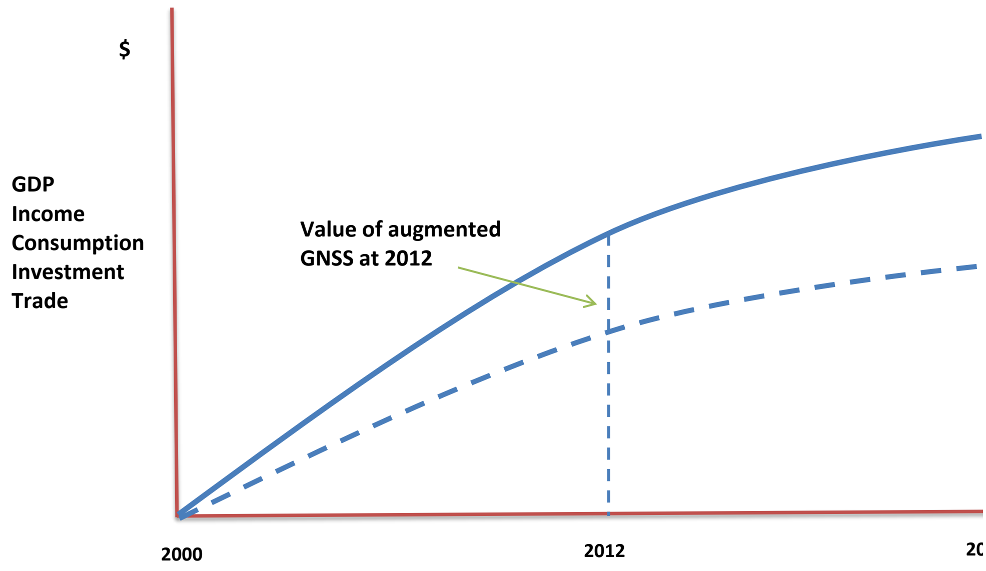
The estimate of value in 2012 represents the accumulated difference between the reference case and the counterfactual that accumulated since augmented GNSS became more ubiquitous. This would be around 2000.

For estimates in 2020 we have assumed that the current situation continues for the counterfactual and that the reference case represents further productivity improvements from further adoption and innovation.

The difference between the 2020 and 2012 amounts represents the additional value created since 2012.

This is illustrated in Figure 9.

Figure 9 **Value of augmented GNSS**



Data source: ACIL Allen

[20] Selective availability was an intentional error introduced into the civilian band of the GPS system for security purposes. It was removed in 1996.

Appendix C Overview of *Tasman Global*

ACIL Allen's computable general equilibrium (CGE) model *Tasman Global* is a powerful tool for undertaking economic impact analysis at the regional, state, national and global level.

There are various types of economic models and modelling techniques. Many of these are based on partial equilibrium analysis that usually considers a single market. However, in economic analysis, linkages between markets and how these linkages develop and change over time can be critical. *Tasman Global* has been developed to meet this need.

Tasman Global is an analytical tool that can capture these linkages on a regional, state, national and global scale. *Tasman Global* is a large-scale computable general equilibrium model which is designed to account for all sectors within an economy and all economies across the world. ACIL Allen uses this modelling platform to undertake industry, project, scenario and policy analyses. The model is able to analyse issues at the industry, global, national, state and regional levels and to determine the impacts of various economic changes on production, consumption and trade at the macroeconomic and industry levels.

CGE models such as *Tasman Global* mimic the workings of the economy through a system of interdependent behavioural and accounting equations which are linked to an input-output database. These models provide a representation of the whole economy, set in a national and international trading context, using a 'bottom-up approach' – starting with individual markets, producers and consumers and building up the system via demands and production from each component. When an economic shock or disturbance such as an increase in a sector's rate of growth is applied to the model, each of the markets adjusts to a new equilibrium according to the set of behavioural parameters[21] which are underpinned by economic theory.

In addition to recognising the linkages between industries in an economy, general equilibrium models also recognise economic constraints. For example, increased demand for labour may increase real wages if there is full employment.

A key advantage of CGE models is that they capture both the direct and indirect impacts of economic changes while taking account of economic constraints. For example, *Tasman Global* captures the expansion in economic activity driven by an investment, and at the same time accounts for the

[21] An example of a behavioural parameter is the *price elasticity of demand* – the responsiveness of demand for a commodity to a change in the price of that commodity. Each of these markets, for example the market for a commodity or a factor such as labour or land or the market for capital goods, is then linked through trade and investment flows.

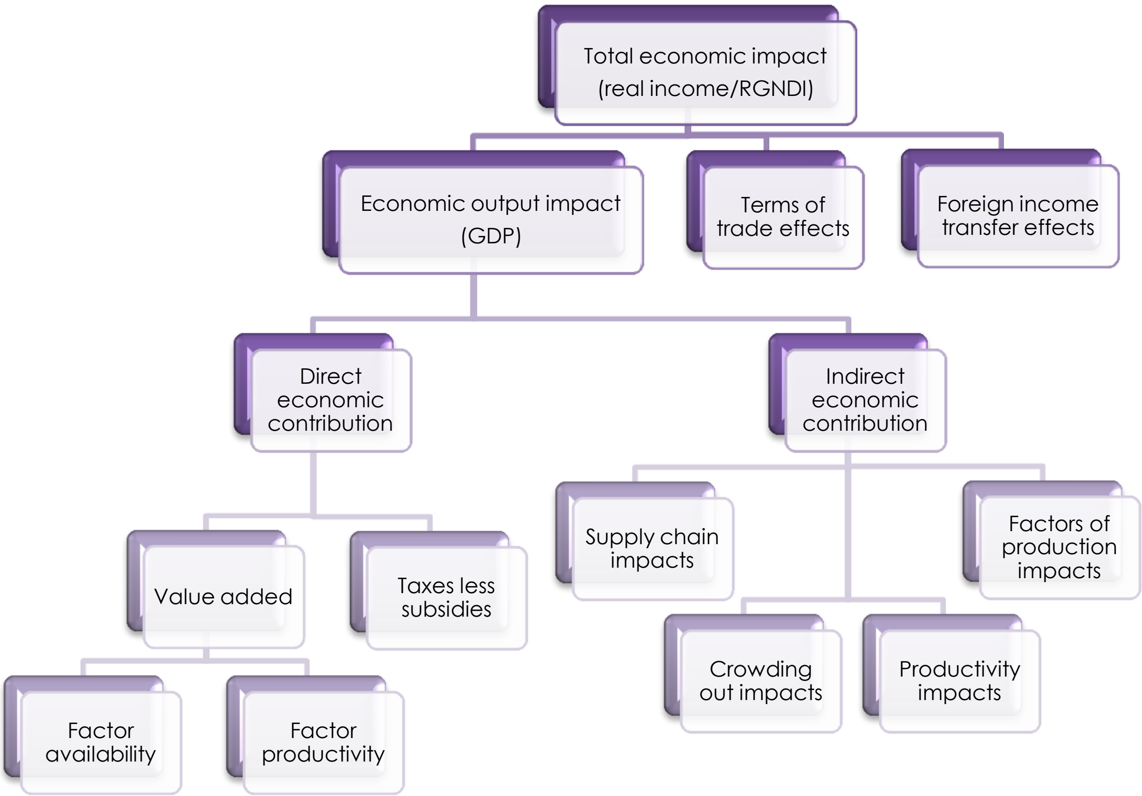
constraints faced by an economy in terms of availability of labour, capital and other inputs. Another key advantage of CGE models is that they capture economic impacts across a wide range of industries in a single consistent framework that enables rigorous assessment of a range of policy scenarios.

The main factors that need to be considered when analysing the economic impacts of a project, policy or technology include:

- the direct and indirect contribution to the economy as a result of the activities associated with a project or application of a specific technology
- any ‘crowding out’ implications, which is where the use of scarce resources in one use means that resources are diverted from other productive activities, potentially ‘crowding out’ those activities by delaying or preventing them from occurring
- any productivity effects generated as a direct result of the policy or project activities – particularly any enduring productivity changes or productivity spillovers to other activities not directly associated with the project or policy
- any changes to the factors of production in the economy including improvements in factor availability or productivity
- any welfare implications associated with changes in terms of trade or foreign income transfers
- whether there is a dynamic element to the size of any of the above effects (due to different phases of a project or a capital accumulation effect for example).

Figure 10 shows these components graphically. Some of these effects may have negligible impact while others may be very significant.

Figure 10 **Estimating the economic impact of a project, policy or technology**



Source: ACIL Allen

For many impact analyses, static estimates of the direct economic contribution and supply chain implications can be obtained through the use of I-O multipliers. Estimating the size of other components using multiplier techniques is either not possible or very complex, as is estimating the economic impacts through time. In contrast, most CGE models are able to estimate all of the components shown in Figure 10 with dynamic CGE models able to estimate the impacts through time. The greater complexity of CGE models generally increases the cost of undertaking analysis compared to using I-O multipliers, but it enables a much broader range of economic impacts to be considered within a single framework.

C.1 A dynamic model

Tasman Global is a model that estimates relationships between variables at different points in time. This is in contrast to comparative static models, which compare two equilibriums (one before a policy change and one following). A dynamic model such as *Tasman Global* is beneficial when analysing issues where both the timing of and the adjustment path that economies follow are relevant in the analysis.

In applications of the *Tasman Global* model, a reference case simulation forms a 'business-as-usual' basis with which to compare the results of various simulations. The reference case provides projections of growth in the absence of the changes to be examined. The impact of the change to be examined is then simulated and the results interpreted as deviations from the reference case.

The database

A key advantage of *Tasman Global* is the level of detail in the database underpinning the model. The database is derived from the latest Global Trade Analysis Project (GTAP) database which was released in 2012. This database is a fully documented, publicly available global data base which contains complete bilateral trade information, transport and protection linkages among regions for all GTAP commodities.

The GTAP model was constructed at the Centre for Global Trade Analysis at Purdue University in the United States. It is the most up-to-date, detailed database of its type in the world.

Tasman Global builds on the GTAP model's equation structure and database by adding the following important features:

- dynamics (including detailed population and labour market dynamics)
- detailed technology representation within key industries (such as electricity generation and iron and steel production)
- disaggregation of a range of major commodities including iron ore, bauxite, alumina, primary aluminium, brown coal, black coal and LNG
- the ability to repatriate labour and capital income
- a detailed emissions accounting abatement framework
- explicit representation of the states and territories of Australia
- the capacity to explicitly represent multiple regions within states and territories of Australia.

Nominally the *Tasman Global* database divides the world economy into 120 regions (112 international regions plus the 8 states and territories of Australia) although in reality the regions are frequently disaggregated further. ACIL Allen regularly models projects or policies at the statistical division (SD) level, as defined by the ABS, but finer regional detail has been modelled when warranted.

The *Tasman Global* database also contains a wealth of sectoral detail currently identifying up to 70 industries (Table C1). The foundation of this information is the input-output tables that underpin the database. The input-output tables account for the distribution of industry production to satisfy industry and final demands. Industry demands, so-called intermediate usage, are the demands from each industry for inputs. For example, electricity is an input into the production of communications. In other words, the communications industry uses electricity as an intermediate input. Final demands are those made by households, governments, investors and foreigners (export demand). These final demands, as the name suggests, represent the demand for finished goods and services. To continue the example, electricity is used by households – their consumption of electricity is a final demand.

Each sector in the economy is typically assumed to produce one commodity, although in *Tasman Global*, the electricity, diesel and iron and steel sectors are modelled using a 'technology bundle' approach. With this approach, different known production methods are used to generate a homogeneous output for the 'technology bundle' industry. For example, electricity can be generated using brown coal, black coal, petroleum, base load gas, peak load gas, nuclear, hydro, geothermal, biomass, wind, solar or other renewable based technologies – each of which have their own cost structure.

Table C1 **Sectors in the *Tasman Global* database**

	Sector		Sector
1	Paddy rice	36	Paper products, publishing
2	Wheat	37	Diesel (incl. nonconventional diesel)
3	Cereal grains nec	38	Other petroleum, coal products
4	Vegetables, fruit, nuts	39	Chemical, rubber, plastic products
5	Oil seeds	40	Iron ore
6	Sugar cane, sugar beef	41	Bauxite
7	Plant- based fibres	42	Mineral products nec
8	Crops nec	43	Ferrous metals
9	Bovine cattle, sheep, goats, horses	44	Alumina
10	Animal products nec	45	Primary aluminium
11	Raw milk	46	Metals nec
12	Wool, silk worm cocoons	47	Metal products
13	Forestry	48	Motor vehicle and parts
14	Fishing	49	Transport equipment nec
15	Brown coal	50	Electronic equipment
16	Black coal	51	Machinery and equipment nec
17	Oil	52	Manufactures nec
18	Liquefied natural gas (LNG)	53	Electricity generation
19	Other natural gas	54	Electricity transmission and distribution
20	Minerals nec	55	Gas manufacture, distribution
21	Bovine meat products	56	Water
22	Meat products nec	57	Construction
23	Vegetables oils and fats	58	Trade
24	Dairy products	59	Road transport
25	Processed rice	60	Rail and pipeline transport
26	Sugar	61	Water transport
27	Food products nec	62	Air transport
28	Wine **a**	63	Transport nec
29	Beer **a**	64	Communication
30	Spirits and RTDs **a**	65	Financial services nec
31	Other beverages and tobacco products	66	Insurance
32	Textiles	67	Business services nec
33	Wearing apparel	68	Recreational and other services
34	Leather products	69	Public Administration, Defence, Education, Health
35	Wood products	70	Dwellings

a A detailed alcohol database and model structure covering 52+ alcohol sub-categories is also available.
Note: nec = not elsewhere classified

The other key feature of the database is that the cost structure of each industry is also represented in detail. Each industry purchases intermediate inputs (from domestic and imported sources) primary factors (labour, capital, land and natural resources) as well as paying taxes or receiving subsidies.

Detailed energy sector and linkage to *PowerMark* and *GasMark*

Tasman Global contains a detailed representation of the energy sector, particularly in relation to the interstate (trade in electricity and gas) and international linkages across the regions represented. To allow for more detailed electricity sector analysis, and to aid in linkages to bottom-up models such as ACIL Allen's *GasMark* and *PowerMar*k models electricity generation is separated from transmission and distribution in the model. In addition, the electricity sector in the model employs a 'technology bundle' approach that separately identifies twelve different electricity generation technologies:

1. brown coal (with and without carbon capture and storage)
2. black coal (with and without carbon capture and storage)
3. petroleum
4. base load gas (with and without carbon capture and storage)
5. peak load gas
6. hydro
7. geothermal
8. nuclear
9. biomass
10. wind
11. solar
12. other renewables.

To enable more accurate linking to *PowerMark* the generation cost of each technology is assumed to be equal to their long run marginal cost (LRMC) while the sales price in each region is matched to the average annual dispatch weighted prices projected by *PowerMark* – with any difference being returned as an economic rent to electricity generators. This representation enables the highly detailed market based projections from *PowerMark* to be incorporated as accurately as possible into *Tasman Global*.

Factors of production

Capital, land, labour and natural resources are the four primary factors of production. The capital stock in each region (country or group of countries) accumulates through investment (less depreciation) in each period. Land is used only in agriculture industries and is fixed in each region. *Tasman Global* explicitly models natural resource inputs as a sector specific factor of production in resource based sectors (coal mining, oil and gas extraction, other mining, forestry and fishing).

Population growth and labour supply

Population growth is an important determinant of economic growth through the supply of labour and the demand for final goods and services. Population growth for the 112 international regions and for the 8 states and territories of Australia represented in the *Tasman Global* database is projected using ACIL Allen's in-house demographic model. The demographic model projects how the population in each region grows and how age and gender composition changes over time and is an important tool for determining the changes in regional labour supply and total population over the projection period.

For each of the 120 regions in *Tasman Global*, the model projects the changes in age-specific birth, mortality and net migration rates by gender for 101 age cohorts (0-99 and 100+). The demographic model also projects changes in participation rates by gender by age for each region, and, when combined with the age and gender composition of the population, endogenously projects the future supply of labour in each region. Changes in life expectancy are a function of income per person as well as assumed technical progress on lowering mortality rates for a given income (for example, reducing malaria-related mortality through better medicines, education, governance etc). Participation rates are a function of life expectancy as well as expected changes in higher education rates, fertility rates and changes in the work force as a share of the total population.

Labour supply is derived from the combination of the projected regional population by age by gender and the projected regional participation rates by age by gender. Over the projection period labour supply in most developed economies is projected to grow slower than total population as a result of ageing population effects.

For the Australian states and territories, the projected aggregate labour supply from ACIL Allen's demographics module is used as the base level potential workforce for the detailed Australian labour market module, which is described in the next section.

The Australian labour market

Tasman Global has a detailed representation of the Australian labour market which has been designed to capture:

- different occupations
- changes to participation rates (or average hours worked) due to changes in real wages
- changes to unemployment rates due to changes in labour demand
- limited substitution between occupations by the firms demanding labour and by the individuals supplying labour; and
- limited labour mobility between states.

Tasman Global recognises 97 different occupations within Australia – although the exact number of occupations depends on the aggregation. The firms who hire labour are provided with some limited scope to change between these 97 labour types as the relative real wage between them changes. Similarly, the individuals supplying labour have a limited ability to change occupations in response to the changing relative real wage between occupations. Finally, there is some scope for movements of workers between states as the real wage for a given occupation rises in one state rise relative to other states. The model produces results at the 97 3-digit ANZSCO (Australian New Zealand Standard Classification of Occupations) level.

The labour market structure of *Tasman Global* is thus designed to capture the reality of labour markets in Australia, where supply and demand at the occupational level do adjust, but within limits.

Labour supply in *Tasman Global* is presented as a three stage process:

1. labour makes itself available to the workforce based on movements in the real wage and the unemployment rate
2. labour chooses between occupations in a state based on relative real wages within the state; and
3. labour of a given occupation chooses in which state to locate based on movements in the relative real wage for that occupation between states.

By default, *Tasman Global*, like all CGE models, assumes that markets clear. Therefore, overall, supply and demand for different occupations will equate (as is the case in other markets in the model).

Greenhouse gas emissions

The model has a detailed greenhouse gas emissions accounting, trading and abatement framework that tracks the status of six anthropogenic greenhouse gases (namely, carbon dioxide, methane, nitrous oxide, HFCs, PFCs and SF_6). Almost all sources and sectors are represented; emissions from agricultural residues and land-use change and forestry activities are not explicitly modelled but can be accounted for in policy analysis.

The greenhouse modelling framework not only allows accounting of changes in greenhouse gas emissions, but also allows various policy responses such as carbon taxes or emissions trading to be employed and assessed within a consistent framework. For example, the model can be used to measure the economic and emission impacts of a fixed emissions penalty in single or multiple regions whether trading is allowed or not. Or, it can used to model the emissions penalty required to achieve a desired cut in emissions based on various trading and taxation criteria.

Model results

Tasman Global solves equations covering industry sales and consumption, private consumption, government consumption, investment and trade. The model therefore produces detailed microeconomic results, such as:

- output by industry
- employment by industry; and
- industry imports and exports.

Tasman Global also produces a full range of macroeconomic results, for each Australian and international region including:

- total economic output – i.e. gross domestic product (GDP), gross state product (GSP) and gross regional product (GRP)
- total employment
- gross national product (GNP)
- private consumption
- public consumption
- investment and savings
- imports; and
- exports.

Appendix D References

Allen Consulting Group. (2008). *The economic benefits of high resolution positioning servcies.* Meblourne: Allen Consulting Group.

ANZLIC. (2012). *National Positioning Infrastructure.* Canberra: The Australian and New Zealand Land Information Council.

ConsultingWhere and ACIL Tasman. (2010). *The value of geospatial systems in local government in England and Wales.* London: Local Goverment Association of England and Wales.

Gambale, N. (2012). *Locata JPS The world's first GPS and Locata receiver.* Canberra: Gambale.

Harcompe, P. (November 2012). *Sydney Satellites - towards ubiquitous positioning infrastructure.* Canberra: Spatial@gov.

Keysers, J. (2013). *Vertical datum transformations across the Australian Littoral Zone.* Melbourne: Cooperative Research Centre for Spatial Information.

Lateral Economics. (January 2009). *Nation Building for the Information Age.* Canberra: Lateral Economics.

UN Office for Outer Space Affairs. (2010). *Current and Planned Global and Regional Navigational Satellite Syetems and Satellite-based Augmentation Systems.* New York: United Nations.

ACIL ALLEN CONSULTING

Precise positioning in the agricultural sector

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

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

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Executive Summary

Australian agriculture competes in global markets some of which are subject to protection, others to production subsidies. To maintain competitiveness it is essential that the industry continues to improve its productivity.

Augmented GNSS services are part of meeting this challenge. They are used in agriculture in combination with other technologies such as remote sensing, auto steer equipment and yield monitoring systems. Collectively these technologies are known as precision agriculture.

The main adoption of precision agriculture in Australia to date has been in broad acre cropping (primarily wheat, barley, oats) and other crops such as cotton. This has been at 10 cm accuracy levels.

Precision agriculture is used in a more diverse range of farms internationally than in Australia. This is largely because intensive livestock farming is more common in other countries than in Australia.

Cattle and calf slaughtering is the largest single contributor to value of agriculture in Australia (18 per cent)[1]. Positioning services in this sector are only likely to be taken up if technological change allows low cost electronic livestock tagging.

Wheat (12 per cent) is the next most important product after cattle[2]. More than 87 per cent of grains farmers use some form of precision agriculture, including 79 per cent who use 10cm accuracy GNSS positioning services.

Productivity improvements are estimated to range between 10 per cent and 20 per cent of production costs.

More precise positioning to 2 cm accuracy offers economic benefits in some other agricultural sectors:

- Cotton, where a large majority of growers already use positioning and are set up to take advantage of greater precision, realising increased savings from application of pesticides and fertiliser; and
- Grape growing, where high precision can improve vine canopy management and harvesting. However because the industry has had limited adoption to date benefits will require new investment and thus take longer to realise.

Extension of 2 cm accuracy augmentation signals would support greater adoption including:

- inter-row sowing of crops, with nutrition and water use benefits
- micro-irrigation (delivery of water to individual plants)

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1 ABS Year Book Australia 2012

2 Ibid.

- increase in the level of benefits realised from reduced overlap in application of fertilizers and pesticides.

The results show that industries in the agricultural sector grew as a result of improvements in productivity from the use of augmented GNSS in precision agriculture as well as in other industries[3]:

- Output in the sector was between $298 million and $466 million higher in 2012 as a result of the use and application of augmented GNSS in the grains industry and elsewhere. This represents between 0.9 and 1.5 per cent of the grains and cropping sectors' output.
- Output is projected to be between $885 million and $2185 million higher by 2020 with further adoption mainly in the grains and livestock industries. This represents around 2.6 per cent and 6.5 per cent of the grains, crops and livestock sectors' output.

Most of this growth is in the grains sector. Barriers to achieving high levels of adoption outside of grains and cotton include:

- In cattle, costs associated with electronic tagging of beasts well exceed benefits potentially realisable from positioning.
- In dairy, adjustment pressures have limited farmers' ability to invest in tracking equipment. There is also crowding out of investment by the changes being pursued through the "future dairy" initiative.
- in grape growing, scepticism about the benefits of positioning
- in horticulture, the small scale and dispersed nature of many of the businesses involved.

In the latter two cases, encouragement of early adopters and documentation of the financial benefits is likely to lead to a similar "S-curve" adoption pattern as that seen in grains over recent years.

As well as economic benefits there are environmental benefits to the use of precise positioning in agriculture including:

- more efficient water use
- reduced runoff of farm chemicals into the environment
- better management of disease outbreaks.

Key findings

- Economic benefits in cropping from the application of precision agriculture supported by augmented GNSS are large, enabling recovery of investment rapidly, sometimes within less than two years.
- Adoption rates in agriculture fluctuate considerably depending on seasonal factors – farmers' ability to invest in on farm productivity improvement depends on a good season. The highest adoption levels have been in the grains and cropping.

[3] The growth in output is a net effect after resources are reallocated across the economy.

- Applications in the grains industry include automatic guidance and controlled traffic farming, variable rate fertiliser application and inter-row sowing. Cost savings of between 10 to 50 per cent have been reported. By researchers.
- Adoption rates in the livestock and horticulture and viticulture areas have been slow to develop.
- Higher adoption rates will be assisted by extension of GNSS augmentation services at the 2 cm level of accuracy. This could be achieved for example through the expansion of CORS networks in Australia.
- Augmented GNSS can also deliver considerable environmental benefits, particularly in more efficient use of water and minimising chemical runoff.

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 agricultural 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 Agricultural sector

The Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) estimates agriculture's share of GDP as 2.0 per cent (farm only) or 2.4 per cent (total agriculture))[4]. Higher figures up to 3 per cent of total GDP are used by some sources.[5]

The value of agricultural production varies considerably year on year due to climate and market volatility. For the year ending 30 June 2010, the gross value of agricultural production, in current prices, was $39.6 billion"[6] In the following year, 2010-11, the gross value of total Australian agricultural production was $46.0 billion.[7]

In recent times, the agricultural commodities with the highest value of production by Australian farmers have been beef cattle, followed by wheat, milk, vegetables, fruit and nuts, sheep and lamb meat, and wool.[8]

The 2010-11 Agricultural Census[9] found that there were 135,000 farm businesses across Australia. The majority of these were involved in specialised

[4] (Agricultural commodity statistics 2012 (chain volume).

[5] As noted by the ABS, "The contribution of agriculture to the Australian economy can be measured in a number of ways" 1301.0 - Year Book Australia, 2012. The range of estimates depends on how wide a definition of agriculture is applied and the methodology for measurement. The DIISRTE publication *Key Facts Australian Industry 2011-12* (www.innovation.gov.au) indicates the share of total industry value added of agriculture, fisheries and forestry combined in 2011-12 was 2.7% and share of GDP 2.4%. The National Farmers Federation estimates agriculture at 3% (Farm Facts 2012).

[6] ABS Cat 1301.0 - Year Book Australia, 2012.

[7] ABS Cat. 7503.0 - Value of Agricultural Commodities Produced, Australia, 2010-11 June 2012

[88] ABS Cat 1301.0 Year Book Australia, 2012

[9] ABS Cat 7121.0, released 29 June 2012

beef cattle farming (28%), mixed grain-sheep or grain-beef cattle farming (9%), other grain growing (9%) or specialised sheep farming (8%).

As noted by the ABS most of Australia's agricultural businesses are "engaged in beef cattle farming, dairy cattle farming, sheep farming, grain growing, or a mixture of two or more of these activities". For mixed farms, farmers' choice of enterprise depends on their individual estimation (based on their own appetite for risk) of likely returns from different products and likely seasonal conditions. This means adoption rates and benefits of positioning are highly variable across the industry.

Agriculture in Australia uses a large proportion of natural resources, including 52% of water use in 2009–10. Spatial information is an increasingly important tool for sustainable management of these resources.

2.1 Positioning and agriculture

Precise positioning with augmented GNSS is a key component of what is often termed precision agriculture – the use of technology to deliver on farm productivity improvements. To date in Australia precision agriculture has primarily been used to deliver improved vehicle guidance, as a result of which better positioning services have been seen largely in the broad acre cropping[10] sector.

Uses include minimising overlap in application of fertilisers and pesticides, lower compaction as farm vehicles' movements are guided precisely to minimise impacts on a paddock, more effective spraying and more precise sowing resulting in lower seed loss. This practice goes by a variety of names including controlled guidance, controlled tracking, or tram tracking. Appendix B provides an outline of the use of GNSS in variable rate and site specific technologies.

The accompanying overview document to this series of reports outlines the infrastructure associated with introduction of augmented GNSS to enhance the accuracy of positioning services.

Agriculture's needs in relation to positioning services are growing. As identified in this study, the current use is primarily in cropping and a level of precision around 10 cm meets present uses. However, productivity through positioning technology could be enhanced through:

- Extending coverage of services in remote areas
- Identifying applications for livestock
- Greater precision down to 2cm to enable emerging applications such as inter-row sowing.

[10] Including grains such as wheat and barley, oilseeds such as canola, lupins (grown as stock feed) and other pulses for human consumption (various varieties of beans and peas).

3 Use and applications of Augmented GNSS in Australian agriculture

3.1 Grains

Grains are the largest segment of the agricultural sector in terms of land under cultivation and second only to cattle slaughtering in terms of value of production. Wheat is the dominant crop, accounting for $4.8b or 12 per cent of the gross value of agricultural production in 2009-10 (ABS, 2012).

Use of precise positioning to date in grains has concentrated in two areas: yield monitoring; and reduction in soil compaction through "tram tacking" of remotely controlled vehicles. This has been possible with 10cm accuracy. Whelan (2012) notes that reducing overlap down to 10cm translates to savings of between $12 per hectare and $23 per hectare on seed, fertiliser and machinery costs at sowing; $1.40 per hectare and $3.20 per hectare on herbicide, fungicide and machinery costs, and total savings of between $13.40 per hectare and $26.20 per hectare (Australian dollars). He also notes that there are associated environmental benefits.

The Grains Research and Development Corporation (GRDC) 2007 report *The economic benefits of precision agriculture: case studies of Australian farmers*[11] provided case studies of Australia farmers adopting variable rate application of fertiliser and realising benefits ranging from $14 to $30 per hectare. Although capital investment was high, from $55,000 to $189,000, the investment was recovered "within 2-5 years of the outlay, and in four out of the six cases within 2-3 years".

Precision agriculture can also enhance productivity by allowing speedier harvest using farm machinery in closer array and also enabling use of machinery in periods of low visibility.

The benefits of auto steer for controlled traffic farming can only be realised through machine guidance, typically accomplished by using high accuracy (±2cm) GPS technology. The key benefits documented in a study of controlled traffic farming on the Darling Downs by Bowman in 2008 included:

- 68% increase in farm gross margin
- 67% reduction in farm labour costs
- 90% reduction in soil erosion
- 93% reduction in Nitrogen loss through runoff
- 52% reduction in CO_2 emissions
- 52% reduction in diesel use
- 45% reduction in repair and maintenance costs (Bowman 2008).

[11] Research conducted by Robertson, Carberry, Brennan, CSIRO Sustainable Ecosystems

Figure 1 **Use of precision guided vehicles**

Source: Omnistar

The GRDC biennial survey of growers shows a significant trend upwards in adoption of precision agriculture:

Table 1 **Grains – survey of growers**

	2010 percentage	2012 percentage
Using some form of precision agriculture technology	77	87
GPS	68	79
Yield monitoring	39	53
Controlled traffic	22	39

Data source: GRDC – interview by ACIL Allen Consulting.

The primary reason for the high rate of uptake in the last two years has been that the cash flow associated with recent good seasons has enabled increased capital investment. Today, precision agriculture is seen increasingly as "the standard way" (GRDC interview) to manage a grains farm. Investments at present are mainly being made in auto steer and yield monitoring equipment. The next steps identified in the adoption curve for precise positioning were variable rate application and satellite imagery for crop management. Adoption of precision agriculture is still underway with a large number of possible future applications with further benefits yet to be realised (GRDC interview).

3.1.1 Benefits of more precise positioning

One of the areas where very high precision (<2cm) has greatest potential for large productivity gains is in inter-row sowing (source; GRDC interview). Sowing between the rows of the previous year's grain crop minimises losses from crown rot, assists germination, enables better stubble management, minimises moisture loss and increases nutrient take-up.

Figure 2 **Inter-row sowing – canola in between rows of wheat stubble**

Source: Whelan 2012t

In this example, a new wheat crop is sown after the canola harvest, meaning the wheat is not sown directly on the stubble of the previous wheat crop. This reduces disease from cereal crop residue, and means the wheat can take up nutrients from the decaying canola roots.

Figure 3 **Inter-row sowing – wheat sown over the canola crop**

Source: Whelan 2012

Based on interviews, the gains in yield are potentially of the order of 10-20 per cent. This translates to a productivity gain of around 1 per cent.

A recent study[12] found that farmers could "profit from inter row sowing via,

- increased production (wheat, lentils, canola) of 0.2 to 0.4 tonne per hectare in stubble retained systems
- reduced costs with less stubble management ($10-25 per hectare)
- increased herbicide efficacy
- reduced sowing problems and improved crop establishment…"

3.2 Viticulture

Based on overseas experience, better vine management and fertiliser application could be expected to increase yields by around 10-15%. These results need to be tested in practice in Australia. The CSIRO project *Precision viticulture, understanding vineyard variability* notes that

> Grape growers and winemakers have known about vineyard variability for as long as they have been growing grapes and making wine…However, without methods for

[12] McCallum, Matt (2011) *Agronomic benefits of inter-row sowing with 2 cm autosteer systems*

> observing or reacting to this variation, they have been forced to treat it as 'noise' and to manage large blocks as though they were uniform…PV addresses variation through the use of enabling technologies, including the global positioning system (GPS) and geographical information systems (GIS), coupled with tools for measuring and monitoring vineyards at high spatial resolution

These possible applications "can be highly profitable" according to CSIRO (2012) but further research is required in order to allow reliable quantification of the possible productivity gains.

3.2.1 Vineyard production and monitoring in New Zealand

Controlled traffic farming has also been adopted in New Zealand as part of vineyard production, specifically in planning the routes taken by vineyard machinery for spraying and harvesting. Augmented GNSS guidance units are used to develop on-screen maps that indicate the optimum route to follow along vine rows (e.g. the best turning circles for harvesters or sprayers to take). An important commercial benefit is the reduction in overlaps. Benefits due to reduced overlap of spraying were estimated in the order of 11% savings on spraying costs[13] . Another benefit is that spraying and harvesting can be undertaken during periods of poor visibility that are affected by weather or the time of day.

Augmented GNSS guidance units have also resulted in time savings due to the ability to monitor the efficiency of production, including monitoring harvester and sprayer route, movement, speed, fuel consumption, and engine temperature. Recent evidence suggests time savings of between 1% and 10% are attributable to monitoring via the GNSS units[14].

Augmented GNSS units also provide data on where in a vineyard certain grape varieties have been harvested from. This allows winemakers to define sub-blocks within a vineyard on the basis of the characteristics of the grapes within them, and to harvest and blend batches of grapes from different blocks. This enhances the traceability of the product, through a record system that can identify sources of components of a wine blend back to their locations within the vineyard[15].

The level of adoption of these technologies in Australia however is low.

3.3 Dairy

Dairy has also been slow to take up precision agriculture. Eastwood (2008) notes that the gap between research and practice has not been bridged and

[13] GPS Equipment Supplier Interview.

[14] Vineyard Estate Owner Interview.

[15] *Lloyd Smith & Peter Whigham 1999:* Spatial Aspects of Vineyard Management and Wine Grape Production. Presented at SIRC 99 – The 11th Annual Colloquium of the Spatial Information Research Centre University of Otago, Dunedin, New Zealand December 13-15th 1999.

attributes this primarily to a lack of a community of practice among dairy farmers in the techniques involved.

Dairy Australia has funded a large and multifaceted project on "Future Dairy" which has a stream on precision dairy, among other things. Even here, the focus is on automated milking rather than use of positioning to improve dairy traffic (movements of cows) as has happened internationally.

For this project we interviewed the largest Australian dairy cooperative, Murray Goulburn. Although their representative thought it was possible some farmers may be using GPS for herd management, he did not personally know of any examples and was not aware of any widespread adoption. Cost pressures and structural adjustment in the industry are possible reasons for low adoption.

3.4 Cotton

Cotton growing in Australia is highly dependent on availability of irrigation water to growers. In recent years plentiful water supply has seen record levels of cotton production, at around one million tonnes. The area planted to cotton is around 500m hectares, primarily irrigated. If ABARES' production forecasts for 2012-13 are realised Australia will overtake India to become the world's second largest cotton exporter after the United States (ABARES 2012). Gross value of cotton production in 2009-10 was $754m.

Smart and Sauer (2011)[16] note that

> "cotton growers in Australia are not only familiar with the term precision agriculture but are also very familiar with the concepts, solutions, and products that are available".

Cotton is a heavy user of agricultural chemicals and pesticides, and precise positioning to reduce overlap and enable accurate site specific application generates large savings. Productivity gains of the order of 1-2 per cent have been reported[17]. Precision agriculture is widely used for application of farm chemicals and more accurate use of farm machinery in harvesting. The use of positioning is combined with electromagnetic induction surveys to identify soil variability and moisture content.

3.5 Beef and sheep

Positioning at either 10 cm or more precise 2 cm levels has no currently feasible widespread application to low intensity cattle and sheep grazing on unimproved pasture, across large areas such as in Australia. The broad range of most Australian beef and sheep farming means that there has been less incentive for farmers to use positioning to determine grazing habits and

[16] In the *Australian Cotton Production Manual – 2011*, Cotton CRC

[17] Cotton Industry CRC

optimise feed availability (the most common applications of GNSS technology for livestock management in other countries with different farm systems[18]).

GNSS has been used as a research tool in studies of livestock movements and habits (for example the University of New England has a number of projects that use tracking devices on stock for research purposes).

There are however potential commercial applications of positioning in future. These include use of pilotless aircraft (drones) for mustering, based on positioning devices attached to each animal – provided barriers of cost and battery life for such devices can be overcome. A study of future potential of precision agriculture to beef cattle found that:

> …remote animal control devices can be used for implementation. This technology relates the GPS position of the animal to spatially fixed coordinates on the ground (the control barrier) and modifies the behaviour of the animal as it approaches the invisible barrier by elicitating an audio or electrical cue from a neck-mounted device. Current research is focused on reducing the size and optimizing the power supply and usage of these devices.[19]

3.6 Sugarcane

Sugarcane for crushing is an important agricultural product in Australia, accounting for $1.4b of the gross value of agricultural production in 2009-10 (ABS 2012). More than 90 per cent is grown in Queensland. In 2009-10 a total of 389,000 hectares of sugar cane was cut for crushing (ABS 2012).

Sugar has been a slow adopter of precision agriculture (see following chapter in relation to barriers to adoption in Australia).

According to the CSIRO recent developments suggest however that sugar is about to move rapidly up the adoption curve:

> Work conducted 10-20 years ago demonstrated that, like other farming systems, sugarcane production may be highly variable at the sub-paddock scale…In spite of this, and for various reasons, whilst growers of grain crops and winegrapes have adopted PA approaches, almost no adoption occurred in the sugar industry.
>
> Over the last two to three years, there has been a rapid uptake of GPS-based guidance and controlled traffic systems as the sugar industry moves towards the 'new farming system' and associated efforts to minimise soil compaction.

[18] Trotter MG, Lamb DW (2008)'GPS tracking for monitoring animal, plant and soil interactions in livestock systems' In *9th International Conference on Precision Agriculture* Denver, Colorado.

[19] Bell, Charmley, Hunter, Archer (2011) 'The Australasian beef industries—Challenges and opportunities in the 21st century' *Animal Frontiers* Champaign Illinois

3.7 Horticulture

The horticulture sector is highly diverse. There is sparse evidence of use of positioning services at present 10 cm levels of accuracy, and the instances identified in a search of the literature appear to be primarily from promotional materials or experimental trials. Examples include:

- Use of unmanned aerial vehicles to monitor tree health and predict yield and harvest times in macadamia orchards – with tree management at sites located on the ground using GNSS coordinates (Horticulture Australia 2012)
- Use in apple orchards of precision guidance systems for robotic vehicles equipped with colour sensors to detect ripeness[20]

As Horticulture Australia (2012) indicates:

> The horticulture industry however has been slower to take up these technologies due to the smaller scale of our farms and the enormous variability across our growing systems (eg. regions, climatic influences, range of plant physiology – orchards vs plantations vs field crops vs protected cropping, seasonality requirements, etc). However the industry is now showing strong signs of interest to learn…precision agriculture is considered a relevant and important emerging technology.

Higher precision positioning services at 2cm accuracy may increase adoption levels. They open up opportunities in areas such as very precise micro-irrigation (drip irrigation targeted to each plant, resulting in minimal water loss), and improved harvest management of high value horticultural crops (for example, fruit for the Japanese export market).

4 Barriers to adoption

Technology diffusion rates in agriculture are slow by comparison with other industries. Farmers will adopt new technologies only if they offer a clearly demonstrated commercial advantage. If early adopters are seen by others in the industry to benefit, then diffusion can be rapid. However, the inherent variability of farming in Australia due to both climate and market volatility can mask the evidence of commercial benefits and impede diffusion.

Ground based survey marks thus remain the most important element of the geographic information infrastructure for agriculture, and use of positioning outside of grain growing is limited. This is though a common pattern of adoption internationally:

> In new countries (or new crop commodities), yield mapping and the option of variable-rate application for inputs are generally what gets things started as a means to save costs, while, in time, product quality comes more into focus[21]

[20] 'Robots to drones, Australia eyes high-tech farm help to grow food' Reuters 27th May, 2013

[21] McBratney, Whelan, Ancev "Future Directions of Precision Agriculture" *Precision Agriculture* 6, 7-23, 2005, Springer.

The USA and some parts of Europe were earlier to adopt precision agriculture than Australia. The recognised adoption pattern is outlined in Whelan (2007):

1. optimise average crop management
2. determine the magnitude, extent and responsiveness of spatial and temporal variability
3. optimise the production input/output ratio for quantity and quality. (to maximize gross margin and minimize environmental footprint)
4. Output quality control and product marketing
5. maintaining resource-base and operation information.

As with all industrial technologies, the pattern of adoption follows an S-curve: slow early experimentation, realisation of benefits and rapid take-up, then levelling off as technology matures. Precision agriculture in Australia is only at the start of that curve.

As noted by Robertson et al (2010), a current barrier to adoption is the perceived complexity of precision agriculture "the relative difficulty of understanding and using a new system and lack of industry capacity to provide specialist technical services to growers can be a constraint to adoption…many growers find the complexity of PA technology, its demands and lack of service make it incompatible with their current farming operations".

As the industry matures, the perceptions about complexity are likely to diminish (assuming Australian farming follows the identified international experience). Grain growers have shown that as benefits are realised, adoption spreads wider. In addition, support services will become more available and at lower cost – an inevitable function of market development.

Coverage of augmented positioning is currently provided either commercially through space based or local RTK systems supplied either by Government or industry itself. In some cases farmers employ opportunistic measures such as the back cast of AMSA's DGPS beacons along the coast. The extension of the CORS network would provide a more consistent availability and range of applications. This should result in increased adoption over the longer term as authoritative augmented signals become available more widely.

5 Estimate of impacts

The impacts of the benefits described above are both direct and indirect. We estimated first the direct productivity impacts on the agricultural enterprises studied. This provided the direct impacts on the sector.

The overall impact on the sector and the economy as a whole depends on resource shifts in the economy. The wider results were derived from the CGE[22] modelling.

5.1 Productivity

ACIL Allan (2008) provided a set of estimates of assumed direct impacts of precision farming on agriculture. Based on the information derived from the case studies undertaken for this report, the impacts outside of grains remain small, but the grains impact has increased considerably due to increased uptake by the industry.

Precision farming requires augmented GNSS. Without it the systems and techniques described in this report would not be possible. Therefore we have credited the benefits to the availability of precision GNSS despite the fact that other technologies such as remote sensing and auto steer and yield monitoring systems are also contributors.

A factor that has to be taken into account is the variability in Australian rainfall and other climatic factors that have a marked impact on both the gains from precision agriculture and the take up rates. In those agricultural sectors more affected by climatic variability the benefits from precise positioning are likely to be lower.

The estimates are based on two scenarios – low levels of adoption, and current potential future benefits if adoption rates are higher and in future become more widespread. The estimates are provided for 2012 and 2020 in Table 2 and Table 3 respectively. The tables list the assumptions.

Table 2 **Productivity impacts of precision farming 2012**

Enterprise	Assumptions	Direct impact (low)	Direct impact (high)
Grains (wheat, barley, etc.)	Controlled traffic, yield monitoring, variable rate application. Adoption averaging 40% across different applications, with 80% of grains farmers adopting at least one GNSS application. Savings in costs of between 12% and 20%.	4.8%	8.0%
Other cropping and agriculture	Low take-up apart from cotton based on evidence from CSIRO and other sources. Adoption 7%.	0.1%	0.3%

Note: Based on case studies and literature review. Precision farming is dependent on precise positioning
Data source: ACIL Allen

22 CGE stands for Computable General Equilibrium modelling. This is discussed in more detail in the overview report.

Table 3 **Productivity impacts of precision farming 2020**

Enterprise	Assumptions	Direct impact (low)	Direct impact (high)
Grains (wheat, barley, etc.)	Low case as above plus adoption of inter row sowing and other yield improvement methods. High case assumes most grain growers adopting full range of precision agriculture techniques. Assumes 40 per cent adoption for the low case and 100 per cent adoption for the high case. Savings in costs of between 12% and 20%.	12.5%	20.0%
Dairy, beef	Adoption of most promising practices overseas. On an assumption that low cost livestock tags can be developed	1.0%	15.0%
Other cropping including sugar cane	Some adoption as lessons from grains spread more widely. High case as for grains – noting that not all cropping will have the same opportunities for adoption of the full suite of applications.	0.2%	15.0%

Note: Based on case studies and literature review. Precision farming is dependent on precise positioning
Data source: ACIL Allen

The low case is the most conservative, and assumes that the levels of diffusion of knowledge and technology has and will remain limited outside of grains and that costs of entry (estimated between $20,000 to $120,000, CSIRO 2007 and Robertson 2010) will remain a barrier to adoption.

5.2 Economic impact

The productivity improvements described above allow the agricultural industries, to grow through greater efficiency and lower costs. The ultimate outcome for the sector, as for the economy as a whole, depends on resource shifts in the economy. The economy wide outcomes are derived from the CGE[23] modelling which is discussed in the overview report.

The results of this modelling for growth in the agricultural sector are shown in Table 4 below.

[23] CGE stands for computable general equilibrium modelling. For more information see the overview report.

Table 4 **Increase in output from the agricultural sector**

	2012 low case		2012 high case		2020 low case		2020 high case	
	$million	Change	$million	Change	$million	Change	$million	Change
Grains	279	1.9%	434	2.9%	773	7.6%	1,377	13.8%
Dairy, beef	18	0.1%	29	0.2%	105	0.4%	791	3.3%
Other cropping (inc sugar cane)	1	0.1%	2	0.2%	6	0.4%	17	1.1%
Total	298	0.9%	466	1.5%	885	2.6%	2,185	6.5%

Note: All amounts in $2013

Data source: ACIL Allen modelling

The results show that industries in the agricultural sector grow as a result of improvements in productivity from the use of augmented GNSS in precision agriculture[24]:

- Output in the sector was between $298 million and $466 million higher in 2012 as a result of the use and application of augmented GNSS in the grains industry and elsewhere. This represents between 0.9 and 1.5 per cent of the grains and cropping output.
- Output is projected to be between $885 million and $2,185 million higher by 2020 with further adoption in the grains and livestock industries. This represents around 2.6 per cent and 6.5 per cent of the grains, crops and livestock sector output.

The grains industry accounts for over 90 per cent of the higher output from the agricultural sector in 2012. This reflects the relatively high levels of adoption of precision farming techniques by the grains sector and the high efficiency gains the industry can achieve as a result.

The "High Case" outcome for 2020 is somewhat speculative, assuming close to 100 per cent take up in grains sector and significant innovation in the use of augmented GNSS in the livestock industry (see Section 3.5). The latter developments are still at the research and development stage.

6 Other economic and social benefits

6.1 Environmental water benefits

Considerable social and economic benefits to Australian farming and the environment more broadly will arise from improved water usage enabled by precise positioning. Precision agriculture allows savings both as a result of better nutrient take up by crops as well as in irrigation. Techniques such as inter-row sowing have an advantage not only for crop productivity but also for water use, because the stubble from the previous crop shades the roots of the growing inter-row crop enabling it to thrive with lower water input. Inter-row

[24] The growth in output is a net effect after resources are reallocated across the economy.

sowing relies on <2cm positioning to enable the new crop to be grown in between the rows established by the precise positioning of the previous crop

Advances in micro-irrigation enabled by precise positioning are similarly likely to deliver considerable water savings for irrigated crops. To date low levels of take up by fruit and vegetable growers can be in part explained by timing: drought at the early stages of positioning technology and relatively plentiful water supply as precise positioning technology has matured. If however drought conditions were to reassert themselves in key locations in the Murray-Darling Basin, precision irrigation is likely to gain greater prominence as one of the ways of addressing the resultant water shortages.

6.2 Other environmental benefits

More precise application of farm chemicals means less runoff, which has considerable benefits for environmentally sensitive regions. Sugar is one of the industries where runoff has been a particular issue due to the impact of fertilizers on fragile reef systems. According to the CSIRO (2012)

> Part of the intuitive appeal of PA is that by maximising the efficiency with which inputs, such as fertilizers, are used, the risk of them being lost off-site is reduced… the sugar industry has begun to use this idea to promote its environmental credentials.

6.3 Biosecurity

Spatial information can also assist in biosecurity control. As noted in ACIL Allen's earlier report on the value of spatial information, it played an important part in managing the spread of equine influenza in NSW in 2007 through publication of maps showing restriction zones (ACIL Tasman 2009).

In future, this kind of application could potentially be combined with stock tags that could deliver an electric impulse to livestock that strayed close to boundaries. This would enable more efficient management of control zones in the event of a serious and widespread animal disease.

Appendix A Variable rate and site specific technology

Variable rate and site specific technology (VR and SST) allow farmers to apply fertiliser and other agricultural chemicals differentially within a paddock depending on data on yields obtained through satellite surveys.

Figure 4 **Sensors mounted on tractor and trailed sprayer**

Source: McVeagh et al. 2012

Case studies on application of nitrogenous fertilisers in Victoria have indicated that farmer adoption rates for VR and SST have been low because "grain growers do not deem variability within a paddock to be sufficient enough to warrant more precise treatment" (DPI 2012).

Whelan (2012) notes that site specific crop management (SSCM) "creates the opportunity to increase the number of (correct) decisions per hectare made about crop management" with large potential productivity gains. He notes that reducing overlap down to 10cm translates to savings of between:

- A$12/ha and A$23/ha on seed, fertiliser and machinery costs at sowing;
- A$1.40/ha and A$3.20 /ha on herbicide, fungicide and machinery costs
- Total savings of between A$13.40/ha & A$26.20/ha and associated environmental benefits.

Appendix B References

ACIL Tasman (2009) *The Value of Spatial Information in Australia*. Canberra.

ABS (2012) *Year Book Australia 2012*, Australian Bureau of Statistics, Canberra

Allen Consulting Group (2007) the *economic benefits of making GPSnet available to Victorian Agriculture* Melbourne

Australian Spatial Consortium ASC (2012) *Australian Strategic Plan for GNSS* viewed 30 October 2012 at http://www.spatialbusiness.org/aus/Industry-News/GNSS-Strategic-Plan

Bowman K. (2008). 'Economic and Environmental Analysis of Converting to Controlled Traffic Farming'. *Proceedings* of the 6th Australian Controlled Traffic Farming Conference, Dubbo, NSW. p.61-69. ACTFA.

Buick, R (2006) *RTK base station networks driving adoption of GPS+/- 1 inch automated steering among crop growers* Trimble Navigation Ltd. Colorado.

DPI (2012) *Understanding Adoption of Precision Agriculture Technologies*, Department of Primary Industries Victoria, viewed 13 September 2012 at www.dpi.vig.gov.au/agriculture.

Eastwood CR (2008) *Innovative precision dairy systems: a case study of farmer learning and technology co-development*. PhD thesis, Land and Food Resources, Agriculture and Food Systems, University of Melbourne

Horticulture Australia Limited (HAL) media release 'Military precision used in macadamia cultivation' at www.horticulture.com.au viewed 12 February 2013

Janssen, V (2010) 'Network RTK adding reliability to precision agriculture' *Australian Farm Journal* November 2010

McBratney, Whelan, Ancev, Bouma (2006) 'Future Directions of Precision Agriculture' *Precision Agriculture* 6 7-23, Springer

McCallum, Matt (2009) 'Inter row sowing and no-till – a good marriage' *Australian Grain* January-February 2009

National Farmers' Federation (2012) *Farmers and Agriculture – NFF Farm Facts 2012* at www.nff.org.au viewed 5 October 2012

Robertson, Llewellyn, Lawes, Mandel, Swift, O'Callaghan and Metz, *Adoption of precision agriculture in the Australian Grains Industry: status, issues and prospects* CSIRO, 2010.

Robertson, Carberry, Brenna (2007) *The economic benefits of precision agriculture: case studies from Australian grain farms* CSIRO, Smart A (2008) 'Precision agriculture in cotton – where can we go from here?' *Australian Cotton Grower* April-May 2008

Smart A and Sauer B (2011) Precision Agriculture in Cotton Farming Systems *Australian Cotton Production Manual*

Trotter MG, Lamb DW (2008) 'GPS tracking for monitoring animal, plant and soil interactions in livestock systems' *9th International Conference on Precision Agriculture* Denver, Colorado.

Whelan, BM (2007) Current Status and Future Directions of PA in Australia *Proceedings of the 2nd Asian Conference on Precision Agricultur*e, Pyeongtaek, Korea, pp60-71

Note: in addition to the references cited, other information has been drawn from the *Proceedings of the 15th Precision Agriculture Symposium in Australia*, 5-6 September 2012, Mildura.

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 and 15 per cent[3].

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 contaminates, 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

- 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[7].

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[8].

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[9].

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 [10]which will be used in their Pilbara

[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[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.

[14] Economic benefits of high resolution positing 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[15]. 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

[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.

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**

Enterprise	Assumptions	Direct impact (Low)	Direct impact (High)
Oil and Gas	Exploration Surveying • 1.9 % increase in efficiency of identified tasks attributable to more efficient coverage steerage 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%	0.0.098%
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**

Enterprise	Assumptions	Direct impact (Low)	Direct impact (High)
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**

	Low estimate	High estimate
	Productivity	Productivity
2012	0.603%	0.944%
2020	1.863%	2.518%

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[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[17].

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

Table 4 **Impacts on output**

		Low case	High case	Low case	High case
		2012	**2012**	**2020**	**2020**
Increase in output	$ million	682	1,084	2,437	3,134
Percentage of total output		0.4%	0.7%	1.1%	1.4%

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.

[16] See overview report for a full description of the CGE modelling approach,

[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].

Figure 1 **Autonomous Haul Truck**

Data source: Rio Tinto

Box 3 **Autonomous technology and Volvo**

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 nature, then it will become increasing 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.[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)

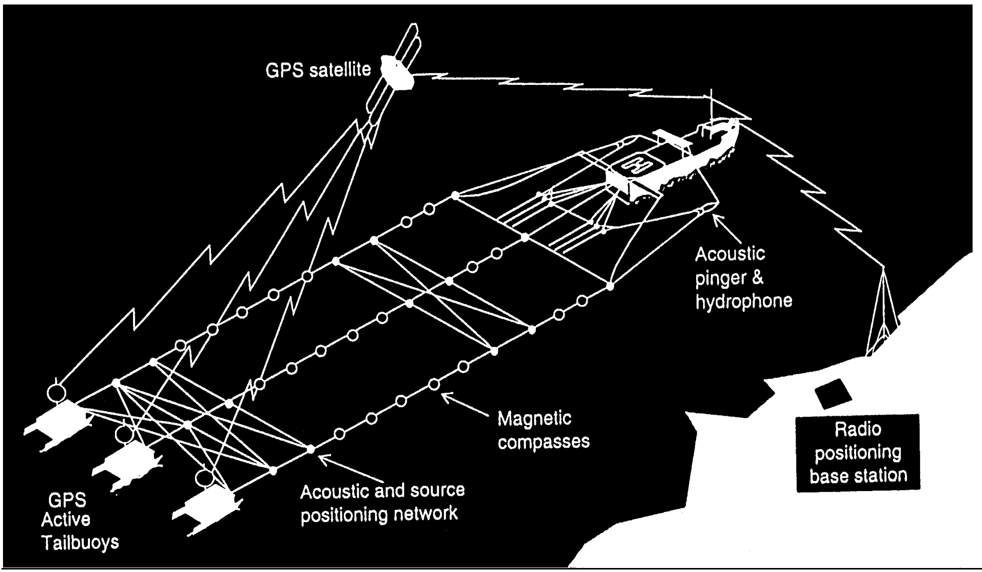
Offshore oil and gas production and exploration is a key area of industry that requires precise positioning to facilitate multiple facets of project lifecycle, but is largely centric to the exploration process. The types of exploration activities that are predominantly supported are Seismic and Bathymetric 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.

[20] Sources: Woodside

Figure 2 **Navigation survey setup for an offshore Survey Vessel (Seismic) utilising DGPS correction**



Data source: 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.

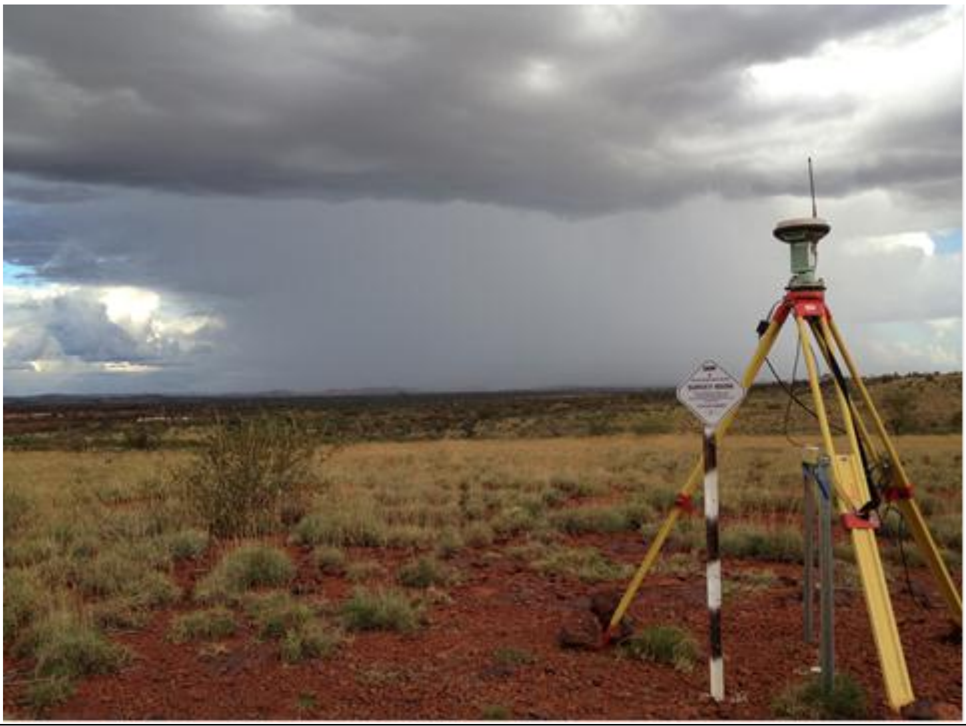
A.4 Mine Site Surveying

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**



Data source: BHP Billiton

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**

Data source: BHP Billiton

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

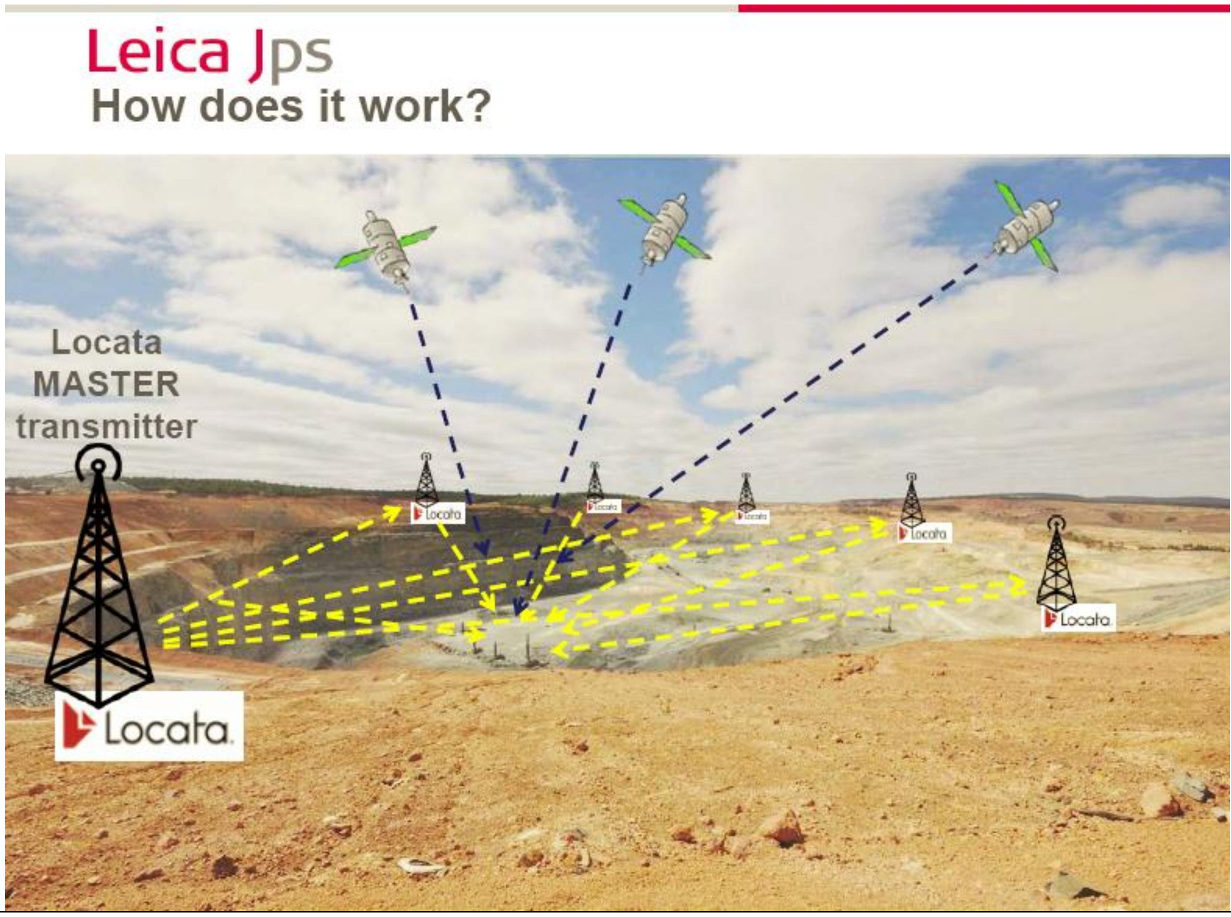
One of the challenging confrontations with mining operations is the supply of ubiquitous positioning across the pit environment. As operations commence in deeper pit environments, GNSS coverage deteriorates due to signal obstruction, resulting in increasing poor performance for machine guidance systems 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.

Figure 6 **Locata based technologies**



Data source: (Gambale, 2012)

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.

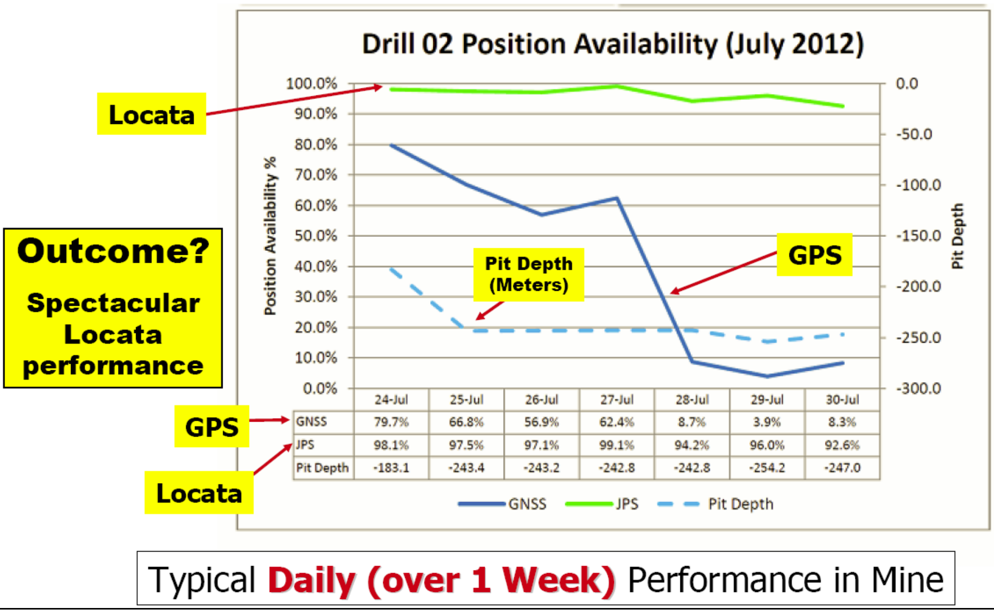
Results suggest that the reliability of positioning coverage through this augmented positioning service is as a dependable at the 92% - 99% level, even in deep pit environments. This is a distinct improvement over the varied GNSS only availability of between 10% - 85 % coverage.

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.

Figure 7 **Type figure title here**



	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul	29-Jul	30-Jul
GNSS	79.7%	66.8%	56.9%	62.4%	8.7%	3.9%	8.3%
JPS	98.1%	97.5%	97.1%	99.1%	94.2%	96.0%	92.6%
Pit Depth	-183.1	-243.4	-243.2	-242.8	-242.8	-254.2	-247.0

Data source: (Carr, 2012)

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 contaminates, wastage and processing bi-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 coal seam gas 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[21] 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.

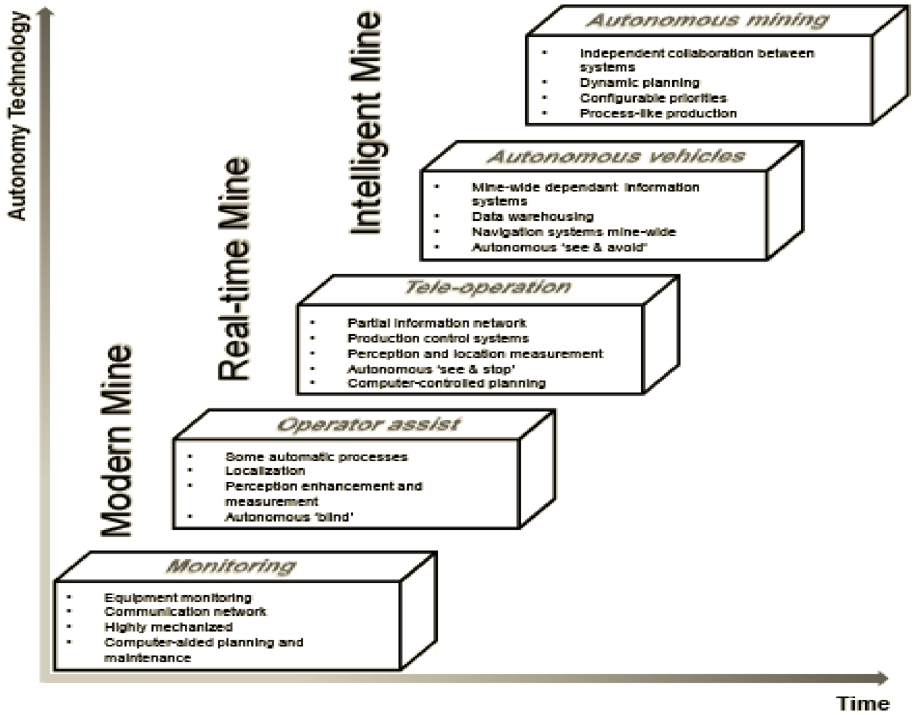
The mining industry is looking into a future of increasing global demand for many of its products, but is constrained by resource grades, energy, labour, and safety, environmental and capital and working-cost considerations. It could be argued that the current outlook is not dissimilar to that of the 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.

[21] Personal Communications Gavin Yeates – BHP Billiton

Figure 8 **Incremental evolutionary phases of autonomous haulage and mining systems**



Data source: Data source: Mine Road Design and Management in Autonomous Hauling Operations: A Research Roadmap, RJ Thompson

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

ABS. (2012). *Productivity tables 5260.0.55.002*. Canberra: Australian Bureau of Statistics.

ABS. (2012). *Value added by industry - ABS series 81550DO002_201011 Australian Industry, 2010-11*. Canberra: Australian Bureau of Statistics.

Allen Consulting Group 2007, *The Economic Benefits of Making GPSnet Available to Victorian Agriculture*, Report to the Department of Sustainability and Environment, July.

Allen Consulting Group 2008, *Economic Benefits of high resolution positioning services*, Report to the Department of Sustainability and Environment, November.

Bellamy, D and Pavica, L 2010, *Assessing the impact of driverless haul trucks in Australian surface mining', Resources Policy* (doi10.1016/j.resourpol.2010.09.002).

Brian S. Fisher and Sabine Schnittger, 2012, *Autonomous and Remote Operation Technologies in the Mining Industry: Benefits and Costs*, BAE Report 12.1, Canberra, February

Carr, J (2012). *Productivity gains at Newmont Boddington using Leica Jps with Locata TechnologyI,* Newmont Boddington Gold Mine.

Carr, j. (2012). *Productivity Gains at Newmont Mine with Leica Jps and Locata Technology.* Newmont Boddington Gold Mine.

Gambale, N. (2012). *Locata JPS The world's first GPS and Locata receiver.* Canberra: Gambale.

http://www.infomine.com/publications/docs/Seymour2005.pdf, Accessed 5 August2008.

Lateral Economics. (January 2009). *Nation Building for the Information Age.* Canberra: Lateral Economics.

McNab, K.L. and Garcia-Vasquez , M. 2011. *Autonomous and remote operation technologies in Australian mining.* Prepared for CSIRO Minerals Down Under Flagship, Minerals Futures Cluster Collaboration, by the Centre for Social Responsibility in Mining, Sustainable Minerals Institute, The University of Queensland. Brisbane.

Pukkila, J and Sarkka, P. 2000. Intelligent mine technology program and its implementation. *Proc. Massmin 2000*, Brisbane, Australia.

Rizos, C. Lilly, B. Gambale, N. 2011, *Open Cut Mine Machinery Automation: Going Beyond with GNSS with Locata,* University of New South Wales.

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

Top, V. (2008). *Productivity in the Mining Industry, Measurement and Interpretation.* Canberra: Productivity Commission.

UN Office for Outer Space Affairs. (2010). *Current and Planned Global and Regional Navigational Satellite Syetems and Satellite-based Augmentation Systems.* New York: United Nations.

Zhao, S. (November 2012). An overview of Australia's peroductivity performance. *Productivity Perspective Conference* (pp. 6,7). Canberra: Productivity Commission.

D.2 Websites:

Applied Mining Tech 2012, *Inertial navigation and Embedded Industrial systems,* http://www.appliedminingtech.com/technologies.html, Accessed 1 September 2012.

Mining Technology 2012, *Miners get spatial awareness,* http://www.mining-technology.com/features/feature71335/, Accessed 20 August 2012.

Rio Tinto, *Mine of the Future ,* http://www.riotinto.com/ourapproach/17203_mine_of_the_future.asp, Accessed 29 August 2012

Sandvick Mining, *Mine Automation Systems,* http://mining.sandvik.com/sandvik/0120/Global/Internet/S003137.nsf/LUSL/SLFrameForm1015DBFF02DE3E407C1257965003C977D?OpenDocument, Accessed 27 September 2012

ACIL ALLEN CONSULTING

Precise positioning services in the construction sector

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

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

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June 2013

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Executive Summary

This report examines the economic and social benefits of augmented positioning services in the construction sector. It forms part of a suite of reports that include an overview report and eleven sector reports.

The construction sector has a need for accurate and reliable positioning data for use in the planning, design, implementation and management of built assets including buildings, bridges, dams, roads and other infrastructure.

Precision GNSS plays a critical role in supporting the efficient flow of data across the construction industry (also incorporating design). Significant uses of augmented GNSS in the industry include:

- construction and engineering surveying
- machine guidance
- asset management.

The construction industry has been an early adopter of augmented GNSS and the levels of adoption are high compared with other sectors. Accuracy of around 2 cm is generally required for most positioning activities although some can operate with accuracy of up to 5 cm.

Precise positioning also helps deliver projects in a more sustainable and equitable way by maximising both the efficiency of the operation and minimising the material wastage associated with major works (especially in regard to earthworks operations).

Output from the construction sector is estimated to have been between $440 million and $710 million higher in 2012 as a result of the use and application of augmented GNSS in activities such as site surveying and machine guidance.

This could rise to between $1,401 million and $2,469 million by 2020 with further adoption of augmented GNSS supported applications and expansion of GNSS services.

Key Findings

- Precision positioning plays a critical role in the construction sector. It facilitates the efficient flow of data across construction and engineering activities.
- Increasingly, larger scale infrastructure projects incorporate augmented GNSS positioning across the complete project design and construction lifecycle and on into asset management once construction is completed.
- Major applications include surveying (both detail and set out), machine guidance and asset management. Most of these applications require accuracy of around 2 cm although some can operate with accuracies down to 5 cm.

- Augmented GNSS has played an important role in improving efficiency in the construction sector. Savings in costs of between 10 and 20 per cent are being achieved with machine guidance and 20 to 40 per cent in construction surveying. This has delivered significant economic benefits to the sector and the economy.
- Gains in the future will depend on increased adoption of existing technologies augmented by further innovation in systems and wider availability of augmented GNSS.
- Extension of the CORS network would underpin the higher outcomes. The densification and improvement of both accessibility and reliability of CORS networks would give greater confidence to many construction operations (such as automated machinery).

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 construction 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 construction industry in the Australian economy

The construction and engineering sector involves a wide array of activities including the design and construction of roads, buildings, rail, ports and bridges and other major infrastructure.

In the 2011-12 financial year, the gross value added contribution of the Australian construction industry was approximately $105.7 billion or around 7.9 per cent of total GDP while total output was $300 billion (ABS). In August 2012 the Australian construction industry directly employed approximately 977,000 workers.

The Productivity Commission's analysis of ABS data found that multifactor productivity in the construction industry was no higher in 2000-01 than twenty years earlier. In contrast, the latest ABS data on productivity shows that construction industry multifactor productivity accelerated to rise by 14.5 per cent in the nine years to 2010/11 (Independent Economics, 2012).

Most of the productivity gains from geospatial and augmented positioning were achieved over the past 15 years due to the commercial emergence of GNSS positional infrastructure (such as VicPos across Victoria) and the rapid improvement and cost efficiency of GNSS technology (distributed via commercial retailers direct to the construction industry).

3 Use of precise positioning in the construction sector

3.1 Construction and engineering surveying

Site surveying is fundamental to all construction and engineering related projects. Survey information provides the foundation to support concept, design and construction and is the building block on which subsequent project phases are based.

GNSS systems have been widely adopted over the last 20 years for site surveying. This has greatly improved both the reliability and efficiency of operations through rapid capture of site information and the fast and reliable set-out of information from design and construction plans.

Typically, surveyors have been at the forefront of GNSS developments and have made considerable investment in both equipment and methodology to maximise the benefits of GNSS. Previous to the introduction of GNSS, surveyors were required to provide and verify extensive control networks and survey via optical instruments (thus reliant on line of site), which more often than not required multiple survey parties and extensive support.

Box 1 **Case studies of savings from augmented GNSS**

Multiple case studies that illustrate these benefits are provided at section A.1 in Appendix A.

The first case study is the Sugarloaf Pipeline project for Melbourne Water which demonstrated the savings in time for surveyors and engineers and improved safety for workers in trench leveling. The East Link Project in Melbourne (2008), Port of Brisbane Motorway in Queensland (2012) and the Regional Rail Link (2012 – ongoing) also demonstrate the savings in time and improved safety available from the use of newer positioning technologies that rely on augmented GNSS. The concrete tie bar project also demonstrates the significant savings in costs and safety from using precise positioning to undertake low tolerance construction activities. This project also highlights the growing integration between surveying and machine guidance methodologies.

Source: SKM

Such survey tasks were considerably slower and often caused significant lag in a number of activities dependent on the timely release of survey data. Whilst these practices are still required on many sites (given limitations on imposed by site environments), the introduction of augmented GNSS has greatly improved the efficiency of survey operations, reduced errors and improved the timeliness of survey data and its flow to other facets of construction projects[1].

The accuracy required for these applications is at the cm level, with some tasks requiring higher accuracy of up to +/- 2 cm. The use of CORS networks or localised reference stations is necessary to provide this level of accuracy.

Whilst levels of adoption vary across engineering and construction activities, the influence and benefit of GNSS has been most apparent in major infrastructure projects. Within these large projects, where reliable and repeatable cm level accuracy is a requirement, the entire project lifecycle (concept, design, construction and maintenance) has been greatly improved

[1] See the Overview Report for or a description of GNSS and augmented GNSS.

through the sophisticated integration of precise positioning through augmented GNSS.

Benefits

Improvements in GNSS technology and improved positional infrastructure have enabled surveyors to collect and process spatial data more easily thus enabling significant on-site productivity improvements. Major benefits include;

- time and efficiency improvements for survey tasks
- accuracy and repeatability of survey information (risk management)
- improved quality control through consistent and repeatable solutions
- reduced labour costs (1 man field survey parties) saving around 30 per cent
- risk management in terms of accurate services location
- ability to provide coordinate information instantaneously
- improved data exchange between design and construction (homogenous data sets)
- infrastructure savings (reduced requirement for survey ground control networks)
- safety improvements through reductions in traffic management requirements.
- integration with machine guidance systems (i.e. earthworks).

A review of recent evidence from the case studies in Appendix A suggests that estimates of productivity benefits of between 20 per cent to 40 per cent remained appropriate. Current adoption rates could range between 60 and 70 per cent.

3.2 Machine Guidance

Machine guidance has been a concept in development for a number of years, initially relying on inertial sensors within its early stages. However, since the introduction of GPS, machine guidance has been able to achieve cm level positioning in three dimensions (3D) and satisfy the more stringent construction accuracy parameters required across projects.

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Box 2 Case studies of savings from augmented GNSS

The case study provided by CR Kennedy and Ultimate Positioning and discussed in section A.2 of Appendix A illustrates the value of precise positioning for machine guidance. The applications described in this case study require accuracy of up to +/- 1 cm in both horizontal and vertical planes. This is now achievable through augmented inertial sensors and GNSS, generally supported by either CORS or localised reference stations.

Source: SKM

Typically, machine guidance is used amongst earthworks across machines such as excavators, bulldozers and grading machines, where GNSS is augmented with inertial sensors to realise precise positioning. As the case study shows, integrated positioning systems can be used in a number of ways to provide levels of machine interaction from indicative to fully autonomous.

Benefits

The benefits of augmented positioning in supporting machine guidance are;

- accuracy improvements
  - Tasks are done correctly the first time around reducing operational inefficiencies, fewer errors and greater specification conformance, even with rookie operators at the wheel.
- reduction of double handling of materials by around 60 per cent
- improved timing of job given less passes required for graders and excavators by around 70 per cent
- less machine wear and tear
- fuel savings of around 25 per cent.
- maximises machine utilisation and reduces downtime
- capital savings
- increased safety.

Machine guidance removes the need for on-the-ground survey set out and construction crew string lining; there are fewer opportunities for potentially dangerous machine / ground-worker interactions. (Machine Guidance 2012). This has the direct benefits of both reducing labour costs and improving health and safety records.

Through combination of these benefits it is estimated that savings of between 10 per cent and 20 per cent are being achieved. Adoption levels are estimated to have risen to around 20 per cent across the sector (see Appendix A).

3.3 Asset Management

Asset management is the terminology applied to any system that is used to monitor things of value. This is particularly relevant to the Construction and Utilities industry which, upon overview, combines to manage a network of (mainly) infrastructure assets worth billions of dollars.

The topic of Asset Management has been analysed in more detail in accompanying utilities report.

3.3.1 Benefits

The central benefits of locating assets via precise positioning techniques are in the ability to reference these assets against each other spatially. The more detailed and accurate the spatial description, the greater the realised benefit.

Using augmented GNSS to assist with the task of asset mapping has multiple benefits for both the direct construction company, but also the organisation which will ultimately manage and run the infrastructure constructed. Asset management techniques primarily employ GNSS for above ground assets, and a combination of other sensors (including GNSS) to locate underground assets. Location information supplied from precise positioning is used to manage aspects such as conditioning, maintenance, distribution of service and performance over the assets lifetime.

These benefits include:

- Data collected can be utilised within a GIS environment.
- The resulting information is spatially correct and can be viewed in its correct position relative to other spatially correct data - eg underground services with respect to property boundaries.
- Assets can be managed more effectively relating to their immediate environments (vegetation coverage surrounding power lines).
- Accurate calculations can be made between the data allowing distances and offsets between structures to be determined.
- The position of assets within the GIS environment can be determined on the ground by setting out the coordinates using GNSS technology. This is of huge importance in locating underground services that no longer have any evidence of position visible on the ground.
- Time spent locating services and waste involved in uncovering assets is minimised.
- Data can be shared between organisations electronically in digital format via email or the internet. Facilitating information exchange through spatial datasets can greatly improve the data management process. This is commonplace amongst larger infrastructure projects such as Regional Rail Link (Department of Transport 2012), East West Link (Linking Melbourne Authority 2012) which utilises a central Geographic Information System to manage and distribute information relating to design and construction via a web browser.

3.4 Emerging Technologies

Perhaps the most crucial aspect of future positioning applications amongst the construction and engineering industries is the change to traditional worksite roles. It is now apparent that the role of the surveyor and machine are increasingly intertwined due to the interoperability facilitated via GNSS positioning.

The traditional role of the surveyor in pegging out construction sites (in particular) earthworks has now changed dramatically as machine guidance allows virtual site data to be loaded directly into controlling systems. That is, both surveyor and machine are now part of the same system, whereas previously they operated independently and the exchange of data between the two resulted in lengthy project lag and reduced quality control.

Augmentation of GNSS within positioning applications largely associated with machine guidance will also continue to improve and facilitate greater automation possibilities as confidence in existing systems develops. Familiarity will play a key part in industry adoption as more and more companies gravitate towards machine guidance and staff become more skilled in operating the systems.

In terms of pure positioning objectives, the majority of currently developed systems are at a stage where they are meeting the accuracy objectives of the construction activities, where environments are suitable. In general the accuracy required is 5 cm in the horizontal with high levels of integrity and reliability.

With GNSS modernisation and increasing availability of GNSS signal through improved constellations, individual systems will be able to further support the vast majority of operations across a wider array of environments. Where potential improvement lies, is in the densification and availability of supporting positional and communication infrastructure to help support stand-alone operations and reduce the requirement (and significant capital spend) for localised reference stations. With such infrastructure improvement, it is likely that smaller operations will increase their adoption rates of this technology.

Another area of development, particularly from commercial providers, is the improvements to satellite delivered corrections through networks such as Omnistar and the ability of Precise Point Positioning (PPP) to realise similar accuracies to those currently delivered by RTK systems[2]. Currently, PPP can deliver positioning at around the +/- 50 mm level however the initialisation times required to converge to this level of precision are far greater than current RTK algorithms.

With the growth and adoption of machine guidance and its benefits to both productivity and safety, machine guidance is often being used as a contractual obligation in many infrastructure projects. It is likely that this trend will continue and machine guidance will be a standard requirement for many construction based projects.

Further applications not yet conceived will also become dependent on such technology as the ability to realise precise positioning in more trying environments develops. Examples such as precise positioning adoption amongst dredging and pile driving applications are current examples of GNSS being employed amongst a niche sector that previously had no confident way to provide precise positioning services.

The concept of visualisation and augmented 3D reality is also in its infancy stages and likely to be implemented amongst construction projects in the near

[2] RTK refers to Real Time Kinematics which is the basis of the CORS system in Australia.

future. Such concepts are driven via the correct capture of spatial data via positioning technologies like GNSS.

Further improvements in productivity are expected as the technology is adopted more widely and as more innovative applications occur.

Details of the assumptions and date supporting the adoption are included in Appendix B.1

4 Productivity and economic impacts

4.1 Accumulated productivity impacts

The estimates of accumulated productivity impacts as at June 2012 are summarised in Table 1. The assumptions on which they are based are provided in the table. These were developed from the estimates of cost savings and adoption levels discussed in this report. The productivity impacts refer to cost savings in the non-residential sector of the construction industry.

Table 1 **Direct impacts**

Enterprise	Assumptions	**Direct impact (low)**	Direct impact (High)
Construction / Engineering Surveying	GNSS used to facilitate site surveying services across both design and construction phases of major infrastructure projects. Productivity impacts of between 0.4% and 0.6% have been used across the non-residential sector. Adoption level of 60% applied	0.300%	0.600%
Machine Guidance	Machine guidance primarily for earth moving. The low and high estimates are based on productivity estimates of 1.5% and 3% with 20 per cent adoption.	0.240%	0.360%

Note: Asset management has been included in the utilities sector report

Data source: Case studies, interviews and literature review.

The estimated impacts in 2020 are summarised in Table 2. The principal difference between 2020 and 2012 is a higher level of adoption. Potential adoption patterns are discussed in Appendix B. We have taken a conservative view of adoption levels taking into account the likely rate of expansion of augmentation services.

Table 2 **Direct impact – 2020**

Enterprise	Assumptions	Direct impact (low)	Direct impact (high)
Site Surveying	GNSS used to facilitate site surveying services across both design and construction phases of major infrastructure projects. Productivity impacts of between 0.4% and 0.6% have been used across the non-residential sector. Adoption level of 70% applied	0.450	0.900%
Machine Guidance	Machine guidance primarily for earth moving. The low and high estimates are based on productivity estimates of 1.5% and 3% with 30 per cent adoption.	0.280%	0.420%

Note: Asset management has been included in the utilities sector report

Data source: Case studies, interviews and literature review.

These subsector impacts translate in to productivity impacts on costs for the sector. These are summarised in Table 3.

Table 3 **Construction sector productivity impact**

	Low case	High case
2012	0.431%	0.766%
2020	0.583%	1.053%

Note: Productivity expressed as a percentage of costs
Data source: ACIL Allen, SKM, case studies, literature research.

4.2 Impact on sector output

The productivity impacts summarised in Table 3 were used as inputs to ACIL Allen's Computable General Equilibrium (CGE) model, Tasman Global[3], to estimate the impact 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[4].

The results from this modelling for output of construction sector are shown in Table 4.

Table 4 **Impacts on output**

		Low case	High case	Low case	High case
		2012	2012	2020	2020
Increase in output	$ million	440	710	1,401	2,469
Percentage of total output	Per cent	0.1%	0.2%	0.3%	0.5%

Note:
Data source: ACIL Allen modelling

The table shows that output in the sector was between $440 million and $710 million higher in 2012 as a result of the use and application of augmented GNSS. This represents 0.1 per cent and 0.2 per cent of total output for the sector.

Output is projected to be between $1,401 million and $2,469 million higher by 2020. This represents 0.3 per cent and 0.5 per cent of total output for the sector. .

The higher outcomes for 2020 will require wider use of advanced surveying systems and machine guidance in the construction sector if they are to be achieved. There is scope for greater use of the latter but it may also require

[3] See overview report for a full description of the CGE modelling approach,

[4] Note that the productivity shocks for other sectors discussed in this report were also entered into the model at the same time.

wider availability of augmented GNSS services and greater compatibility between services in the future.

Appendix A Case Studies

A.1 Construction surveying and set out

A.1.1 Sugarloaf Pipeline

The Sugarloaf Pipeline Project was a $625 million project delivered by Melbourne Water's first major Alliance comprised of Melbourne Water, Sinclair Knight Merz, GHD and John Holland Group. The Alliance was responsible for all planning and environmental assessments, engineering design, community and landowner consultation, project management and construction associated with the Project.

The sugarloaf pipeline involved laying approximately 5,500 pipes in nine months over 70km, drilling an 826-metre-long tunnel, building two pump stations, a power substation and a hydro-electricity plant. The project was completed in 2009 through an alliance of both design and construction companies with precision GNSS and site surveying being a common technology across the entire project lifecycle[5].

Figure 1 **3D visualisation of Sugarloaf pipeline**

Data source: SKM and John Holland

Site surveying duties included activities from the capture of initial topography, the definition of site boundaries for purposes of easement creation, the capture of as-built pipeline information, survey of trench depths and the survey of batters and other features for earthworks. On-site surveyors were able to

[5] Smith, Steve. Anglin, Tania. Harrison, Karen 2010, *Sugarloaf – A Pipe in Time*, Melbourne Water

respond to both design and construction requests and mobilise quickly in the field (often in one person parties), connecting to localised reference stations to provide centimetre level positioning to a wide array of tasks. The use of GNSS greatly improved the survey coverage without the need to establish large (and expensive) survey control networks.

Given the accuracy and reliability of the precision GNSS systems used, there were fewer requirements for rigorous survey reductions, resulting in fewer calculation errors. This reliability greatly reduced the time of surveyors to provide and capture information which benefitted both design engineers and constructors reliant on survey information to proceed with operations. Site survey operations formed a huge component of the risk management of the project.

The project also introduced several safety-focused innovations to the project, including the remote-controlled trench leveller used for laser-levelling of bedding material in the trench, eliminating the requirement of works to occupy the trench itself.

Figure 2 **Trench level and pipeline laying guidance**

Data source: SKM and John Holland

It has been estimated that the savings in surveying and set out for the project were around 10-20 per cent.

A.1.2 The East Link project

In its 2008 report ACIL Allen documented information on the East Link Project (ACIL Allen, 2008). The work on this project remains relevant in 2012 but has been updated to 2012.

The EastLink project in Melbourne involved construction of a 45 km freeway-standard road connecting the city's eastern and south-eastern suburbs. Total project costs were estimated at $2.5 billion. The construction of the paved road, more than eighty bridges, seventeen interchanges and 1.6 km three-lane twin tunnels was expected to be completed in three and a half years.

Major construction commenced in March 2005 with completion delivered in 2008. According to the key contractor's General Manager for Project Wide Delivery, smart technology was expected to be the key to achieve productivity gains in such a short time frame.

With 7.5 million metres of soil to be moved, the traditional method of putting stakes in the ground to guide the machinery was never going to be satisfactory. Trimble technology has addressed that problem for us and created many opportunities to increase productivity on the project.

This is a good example of how technology supported by precision GNSS has made a significant impact in road construction during the recent past in Australia. Discussion with distributors of Trimble GPS based products confirmed that an overall saving of 10 per cent would be a reasonable estimate. Savings arose from a combination of more efficient use of labour and faster completion of tasks.

One of the advantages of using spatially enabled equipment was that the sub grade of the road could be poured much more accurately – this is normally 2 inches thick and one of the steps of completing a road is to pour concrete to bring the road surface up to predetermined levels. It was suggested that in terms of concrete alone, 0.5 cm of extra paving over the length of the road has been avoided by using accurate spatial information.

Estimated at approximately $100 per square metre of 2-inch concrete, a reduction of 0.5 cms translates into a saving of about $20 per square metre. The East Link involved laying 2 million square metres of paved road, so on this account alone a saving of $40 million is estimated to have been achieved for this project.

A.1.3 Benefits

Improvements in technology have enabled surveyors to collect and process spatial data more easily thus enabling significant on-site productivity improvements. Site surveying benefits can be analysed independently to other construction and engineering processes, however the true benefits often need to be evaluated as part of a larger project life-cycle assessment and become inclusive of other facets of positioning such as machine guidance. The benefits include:

- time and efficiency improvements for survey tasks
- accuracy and repeatability of survey information (risk management)
- improved quality control through consistent and repeatable solutions
- reduced labour costs (1 man field survey parties)
- risk management in terms of accurate services location

- ability to provide coordinate information instantaneously
- improved data exchange between design and construction (homogenous data sets)
- infrastructure savings (reduced requirement for survey ground control networks)
- safety improvements through reductions in traffic management requirements.
- asset management and maintenance of as built data.

A.1.4 Productivity Estimates

There are many associated productivity benefits for applications of precise positioning across both construction and engineering site surveying.

With improving procedure, technology and availability of GNSS services, site surveying applications are improving project productivity all the time, however for the purpose of this assessment it is assumed that these benefits are only marginally more productive and the rate of increase minimal given the already advanced state of surveying applications, thus many estimates have been projected from industry figures over the previous five years.

- reduced labour costs (up to 50%)
- improvement in timeliness of survey operations reducing project lag (up to 75 %)
- reduces requirements for survey office data reductions
- productivity benefits of between 20-30% (Allen Consulting, 2008).

Consultations undertaken by the Allen Consulting Group found that fees charged by field surveying companies are approximately 50 per cent lower for large projects and 20 per cent lower for smaller (2-3 day) projects when precision GNSS (Allen Consulting Group 2012).

Reduced labour requirements on major infrastructure projects (such as Melbourne’s East Link) required up to 10-12 less on-site staff (Allen Consulting Group, 2008), this is similar in nature to more recent (and ongoing) infrastructure projects including Regional Rail Link (over $4 billion total investment) which heavily utilised precision GNSS for extensive feature design survey information, construction set out survey and asset management post construction.

The latest update suggests that the savings of between 20 per cent and 40 per cent remain appropriate. However adoption is now higher since that estimate was made leading to higher industry wide outcomes. Adoption is estimated to be around 60 per cent and is likely to be higher.

A.1.5 Adoption Costs

The adoption costs associated with site surveying GNSS systems range between $50,000 to $80,000 for the purchase of base and rover RTK enabled systems. Such costs can be significantly reduced by purchasing a greater number of GNSS rovers which can either be connected to the single localised on-site reference stations or the wider CORS networks.

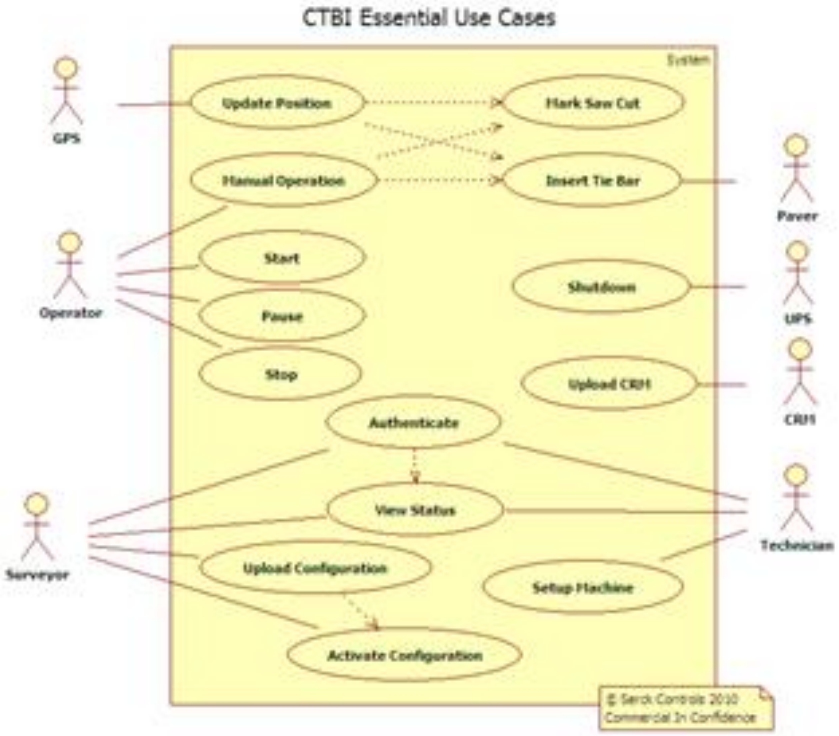
A.1.6 Concrete Tie Bar Insertion Project (innovation project)

This case study was provided by Schneider Electrics and Leighton Contractors.

Road pavement construction activities consist of a requirement to reinforce concrete with steel tie-bars placed at strategic locations throughout the concrete pouring stage. As such, there is a requirement to position tie-bars (and saw cut non-reinforced areas) at appropriate intervals to the cm level of positioning. Currently this procedure is carried out manually via the survey and mark-up of reinforcement points and the manual alignment of the appropriate machinery over the marked region. Opportunity costs are realised by the construction company by meeting KPI's associated with the correct positioning of tie-bars.

The automation of this procedure would see the direct upload of reinforcement tie-bar localities within appropriate CAD software which is then used to guide the machine via its GNSS positioning system to its correct insertion point. The sequencing of the use of precise GNSS is illustrated in Figure 3. Augmented GNSS is required to achieve these results at an accuracy of 2 cm.

Figure 3 **GNSS assisted tie bar sequencing**



Data source: Schneider Electrics (Concrete Tie Bar Insertion proposal to Leighton Contractors)

The benefits of such application not only include the saving in opportunity costs for the contracting constructor (though meeting KPI's) but also the reduction in labour costs (manual machine operator) and reduction in ongoing concrete maintenance costs given the correct reinforcement of the constructed area will result in reduced cracking and load stresses.

Overall adoption costs of system installation were quoted at approximately $100,000.

A.1.7 Productivity Estimates

The improvements in productivity identified in the case study include:

- reduced ongoing maintenance cost for constructed features
- reduced opportunity costs for constructors (meeting KPI's)
- improved health and safety as a result of reduced requirement for manual tasks and less on-site staff.

Using GNSS machine guidance and other innovative techniques the Port of Brisbane Motorway was completed six months ahead of schedule (30% reduction in time required), with a 10% reduction in total project costs, 10% reduction in traffic management costs and 40% reduction in lost time injuries (Higgins 2012).

Other productivity realisations and benefits relating to the reduction of on-site survey staff include the seamless exchange of data between design and construction (realised by uploading set-out site information to automated earth moving machines) and also the reduction in requirement for traffic management services.

A.1.8 Adoption Costs

Adoption costs of machine automation will be around $25,000 to $20,000 for appropriate positioning system, with software and development costs to the guidance system will be around $70,000.

Given the fact that many areas of construction, particularly roads, are not covered by existing positioning infrastructure, there is more often than not a requirement to establish suitable reference stations and control throughout the larger extents of the proposed construction site.

This often results in the establishment of large survey control networks that require extensive surveying to provide ground marks to both associate semi-permanent reference (base) stations and to provide on-site calibration to automated guidance systems (to ensure integrity).

A.2 Machine Guidance

This case study was provided by CR Kennedy and Ultimate Positioning.

Machine guidance has been a concept in development for a number of years, initially relying on inertial sensors within its early stages. However, since the introduction of GPS, machine guidance has taken on an extra dimension and is now satisfying the more stringent construction accuracy parameters and currently realising many project benefits.

Typically, machine guidance is used amongst earthworks across machines such as Excavators, Bulldozers and Grading machines, however there are numerous examples (such as the concrete reinforcement machine discussed earlier) that implement either indicative or fully autonomous systems.

Machine guidance can exist in numerous forms and does not necessarily imply the integration of GNSS. Industry standard two dimensional (2D) machine automation systems rely solely on inertial sensors within the machine itself to provide positioning information back to the central controller. However, it is with the advent of 3D machine automation, that GNSS is playing a critical part. 3D systems incorporate 2 GNSS antennas to provide absolute positioning (as opposed to relative positioning of the inertial sensors) at a rapid high rate (between 20 and 50 hz). Typically, two GNSS antennas are fixed to masts behind the particular machine (the second antenna is to provide orientation information), and position of boom, mast, shovel or bucket is positioned via a combination of defined offsets and inertial sensors.

Figure 4 **3D Machine Guidance system setup on excavator**

Data source: C.R.Kennedy (Leica Distributor)

Current accuracy estimates of 3D systems suggest that machine guidance within excavation activities can safely achieve between 10-50mm. Obviously, the more precise the operation, the more rigorous the system and internal control parameters (constraints) used to guide it.

Figure 5 **3D Machine Guidance Interface setup on excavator**

Data source: Ultimate Positioning (Trimble Distributor)

Under a 3D system, the achievable accuracies are often determined by the supporting GNSS reference stations. Typically, localised base stations are established and deliver RTK corrections (at high rate) to the adopting machines. However, there is a gradual trend towards the use of CORS networks to supply correction information. The conservative estimate for the use of CORS within machine guidance is at 2 to 5 per cent.

Under CORS based correction systems, the accuracy is not quite as tight (typically between 30 to 50mm) as with localised site base stations that can in most cases achieve results around the +/- 20mm or better. This is largely to do with the distance to these reference stations as when in excess of approximately 50km, the achievable accuracy and reliability of the RTK solution reduces past the tolerances typically required for earthworks. With further densification of CORS, delivery of Precise Point Positioning (via improved clock and orbit data products) and improvements in communications, this accuracy can be greatly improved.

The data flow from design to construction is still one of the most critical aspects of any machine guided operation. Any operation can only achieve accuracies to the stated quality of the supplied data, thus the role of the surveyor and designer become crucial to the overall operation. There is a distinct trend within construction that now intertwines the role of surveyor and machine. This is largely facilitated by the direct and seamless transfer of data supported via GNSS positioning.

A.2.1 Benefits

The benefits identified include

- accuracy improvements - Tasks are done correctly the first time around reducing operational inefficiencies, fewer errors and greater specification conformance, even with rookie operators at the wheel.
- reduction of double handling of materials

- improved timing of job given less passes required to (grade, excavate etc.)
- less machine wear and tear
- reduction in fuel and operational costs
- maximises machine utilisation and reduces downtime
- capital savings
- increased safety:
  - Machine guidance removes the need for on-the-ground survey set out and construction crew string lining; there are less opportunities for potentially dangerous machine / ground-worker interactions. (Machine Guidance 2012).

A.2.2 Productivity Estimates

The productivity estimates provided by the case studies were:

- time savings of up to 70%
- reduction in double handling up to 60%
- reduction in the number of passes and re-work by up to 70%
- fuel savings of approximately 25%
- labour saving; reduced on-site surveyor support (up to 95% across certain activities)
- overall estimations of combined productivity benefits between 10-30% (application dependant).

The realised productivity benefits of machine guidance systems are dependent on both the experience of the operator and the application to which it is being used. An indicative figure quoted by suppliers of machine guidance systems suggest that there is at a minimum 25% productivity benefit across industry[6], with many applications realising much higher figures.

The University of Reykjavik conducted a number of trench excavation studies in 2008 utilising machine guidance through excavators and found that on relatively simple construction (earthworks) activities for trench digging, there were a number of quantifiable productivity benefits (see Figure 6).

[6] note this does not include structural construction

Figure 6 **University of Reykjavik excavation comparison tables**

Comparison of time between methods						
	Traditional way			New way		Difference between methods
	Excavation of trench	Finishing of trench	Sum	Excavation of trench	Sum	
Time	04:18:30	04:14:00	08:32:30	06:35:00	06:35:00	01:57:30

22,93 % savings in time

Comparison on the work of the surveyor between methods						
	Traditional way				New way	
	Stakeout for trench	Control measurement	Unforeseen measurement	Sum	Stakeout for trench	Sum
Time	00:39:00	00:26:00	00:20:15	01.25:15	00:02:00	00:02:00

97,65 % savings in time

Comparison on use of fuel between methods						
	Traditional way			New way		Difference between methods
	Excavation of trench	Finishing of trench	Sum	Excavation of trench	Sum	
Time	196 L	151 L	347 L	270 L	270 L	77 L

22,19 % savings in fuel

Data source: University of Reykjavik

Earthworks represent up to approximately 10-15% of non-residential construction activities (Allen Consulting 2008 and SKM estimates). The benefit from machine guidance in earthmoving is approximately 10 per cent to 30 per cent. Based on this is an estimate of non-residential construction industry benefit of approximately 1.5 per cent to 3 per cent has been used for the purposes of economic modelling.

Productivity is achieved through a number of scenarios. Reduction in on-site staff, including surveyors, who would previously be required to supply cut and fill pegs to any earthworks operation is a key component of saving. However it is the reduction in material double handling that produces the most obvious savings to any earthworks. Previously, without guidance controls, the effectiveness and efficiency of operation were reliant on the experience of foreman and operator which still resulted in plentiful double handling. With the advent of guidance systems, relatively inexperienced operators can be more effectively guided through the task to maximise the efficiency of the earthworks. This is also a crucial point to note given the relative skill shortage the construction industry is seeing in experienced machine operators.

Machine guidance systems also facilitate applications that weren’t previously possible, such as pile driving from barges as part of the dredging and port construction services. Examples like this suggest that as machine guidance is more readily adopted more and more applications will be discovered.

A.2.3 Adoption Costs

Benefits of machine control clearly outweigh the initial investment and are precisely why the technology has been rapidly adopted throughout several industries (mining, civil engineering, and construction) given the savings of efficiency through the benefits described above.

The typical machine guidance costs range between $60,000 and $80,000 per machine based on current estimates provided and dependant on exactly what machine the system is used to control (i.e. graders are more expensive to fit than dozers). The vast majority of the adoption costs are centred around the GNSS hardware, with 2D systems (based solely on inertial sensors) ranging between 20 and 30k to fit out, but increasingly becoming phased out amongst new markets.

Another key component of the initial investment is the establishment of localised spatial data infrastructure and communication equipment (i.e. radio signals). This tends to be the industry standard at the moment, however with densification of CORS and improvement in communication coverage, localised base stations may well be surpassed in many areas where coverage is sufficient. This could save approximately $20,000 to $30,000 capital investment.

Currently within the construction industry it is estimated that there is up to 2,500 machines across Victoria alone with indicative or full machine guidance systems. Across Australia this estimated is projected to be around the 10,000 mark. With increasing exposure to machine guidance, there is an upward trending rate of adoption, estimated at around 10-15% per annum. For the purposes of modelling we have assumed a modest increase to 30 per cent by 2020 recognising some constraints with availability of suitable augmentation signals in some areas.

A.3 Limiting Factors

With lack of supporting infrastructure, precision GNSS often has to depend on localised GNSS reference networks that can be more expensive to setup, maintain and administer. Accordingly, wide scale GNSS augmentation tends to be limited to large infrastructure projects and is not as readily available to smaller construction projects (given associated costs). Smaller projects within some metropolitan and regional areas can be supported via existing positional infrastructure, particularly in New South Wales, Victoria and South Australia, however most projects could benefit greatly from extension and densification of CORS networks.

There is also a limitation in many applications of machine guidance given the increasing reliance of precision GNSS as a guidance sensor. This can cause frustration and downtime given that GNSS is not always applicable to some site conditions (especially in areas where satellite coverage is greatly obscured – such as within large trenches). This is somewhat alleviated by the introduction of other sensors within guidance systems. In the longer term other technologies such as Locata may address some of these gaps in service. GNSS modernisation will also provide more dependable and available signals and constellation geometry to support operations.

Appendix B Adoption

It is apparent that there is already significant take-up of a number of precise positioning applications throughout the construction industry including both site surveying and machine guidance, which are increasingly becoming convergent. Whilst this is largely constrained to larger scale infrastructure projects, the increasing availability of both precise positioning services and machine guidance systems is lending itself to an ever increasing adoption rate, with large economic benefits being realised by the companies at the forefront.

B.1 Adoption Factors

Adoption is driven by a number of factors. More broadly speaking, the classic textbook reference by Rogers (1964) identified a five-step decision process involved in technology adoption and diffusion:

- Knowledge – potential adopter becomes aware of an innovation but has no particular opinion of it (this could be via advertising or through word-of-mouth)
- Persuasion – the potential adopter seeks further information to help form an attitude toward the innovation
- Decision – the potential adopter engages in activities that lead to a choice to adopt or reject the innovation (the process is internal to the person and can be difficult to measure empirically; however considerations of price and perceived usefulness/necessity will play into this decision)
- Implementation – the innovation is adopted and put into use (e.g., user installs geospatial data software or uses car navigation aids)
- Confirmation – person evaluates the results of an innovation-decision already made which may affect decisions such as whether to continue using the innovation or return to previous status quo (e.g. remove software or return car navigation aid).

Some of the factors that the research suggests are important in the further adoption of precise positioning technologies are discussed below.

B.1.1 Ubiquitous Positioning

Given the majority of adoption of positioning applications is for infrastructure and earthworks related activities, there is a whole realm of further potential within the structural construction sector. Similar to mining, advances in positioning technology may further the likelihood of concepts such as indoor positioning, or at least positioning in areas obstructed from satellite view. Examples of the Locata terrestrial based system facilitating deep pit activities maybe a concept explored for that of structural construction in the future, however as it stands, the adoption of GNSS is generally limited to open sky large scale construction endeavours largely associated with mass infrastructure development.

B.1.2 System Interoperability

The increasing convergence of surveying site duties and machine guidance will further enable adoption of precise positioning within the immediate future. Already great progress has been made by position system companies to ensure the interoperability and exchange of precise site data between survey design and machine guidance.

B.1.3 Industry Standards

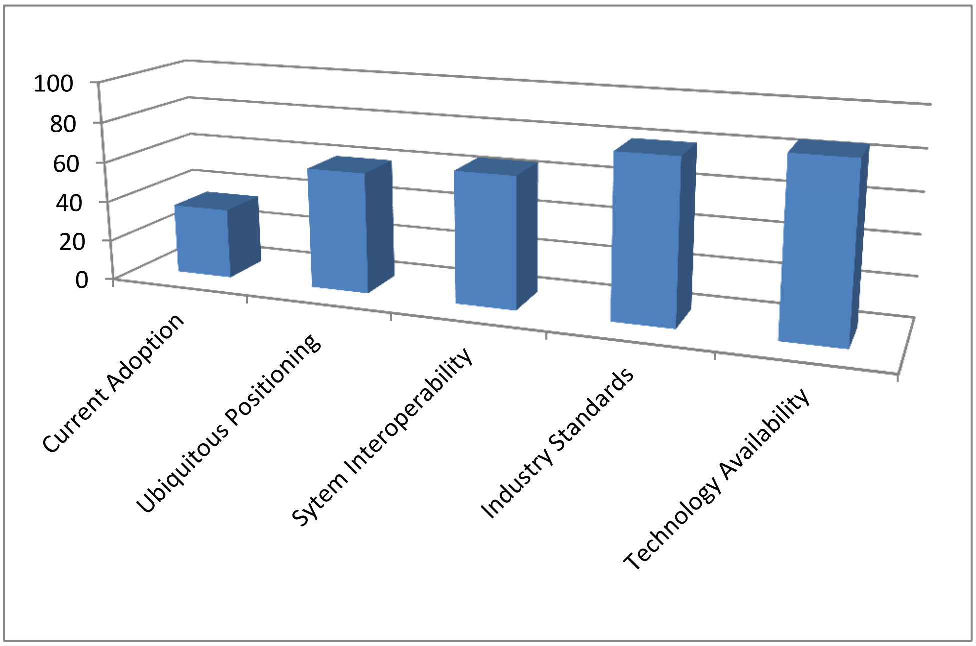
An important adoption factor to be discussed is the development of industry standards that may well require a number of construction stakeholders to conform to machine guidance project implementation as part of the conditions of contract. Such stipulations will drastically increase the adoption rates of the technology and encourage smaller players to make the investment into more advanced systems.

B.1.4 Technology Availability

Larger companies at the forefront of large-scale infrastructure development have already made significant investment into machine guidance to improve the efficiency of their operations. Such large scale investment has yielded technological innovation and integration and as a result companies have started to realise large benefits. Smaller contracting companies are still somewhat behind in the adoption of automation technologies given the up-front costs needed to secure the technology and integrate it into working practices.

Figure 7 demonstrates the estimated rise in adoption level as the various adoption factors are overcome through developments.

Figure 7 **Adoption levels and factors**



Data source: SKM

The adoption factors previously discussed and indicated within figure 11 are seen as the major impediments to adoption. As these are partially or fully overcome there will be a direct correspondence with construction adoption of positioning systems and technologies. The table below is speculative but an attempt to project the likely technological and structural advances in positioning adoption factors.

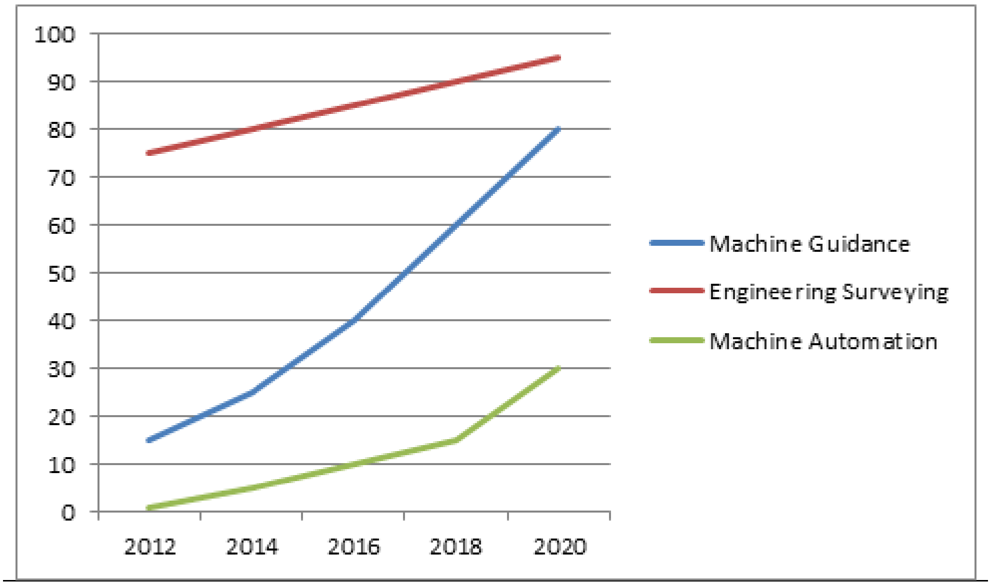
Table 1: **Estimated Timeframe for overcoming adoption factors – Construction**

		Optimistic	Medium	Conservative
Ubiquitous Positioning	2014	2018		2025
System Interoperability	2014	2018		2020
Industry Standards	2014	2018		2025
Technology Availability	2014	2018		2025

Data source: SKM

The graph below displays the likely increase in adoption of GNSS precise positioning technologies amongst the Construction sector. Three curves have been estimated based on the implementation of GNSS positioning amongst construction applications identified throughout the case studies

Figure 8 **Adoption Curves**



Data source: SKM

Appendix C Social and Environmental

Any major construction project is going to have an influence on its immediate environment. This is an inevitable consequence of development. Obviously, the key aspect of existing and future development projects is to minimise the immediate negative implications and maximise the positive influence of the development.

Precise positioning help deliver projects in a more sustainable and equitable fashion by maximising both the efficiency of the operation and minimising the material wastage associated (especially in regard to earthworks operations). This is achieved, via integrated positioning systems that aid machine guidance, GNSS, in particular works to reduce direct impacts such as fuel use, carbon emissions and excessive material waste.

There are many potential social impacts of construction and engineering operations. The prime examples include the impact of large scale infrastructure developments on the immediate community. Such impacts are often vigorously debated by community representatives with particular concerns expressed frequently regarding impacts such as sustainability, people displacement and inconvenience. Effective management and efficiency improvements (via machine guidance and GNSS precise positioning) will help alleviate some of these direct concerns, however construction and project delivery is inevitably fraught with larger scale opposition.

The ability of works to relay information to the community (via spatial information), is of particular importance to any project. An example being the update of progress and impact on the Sugarloaf pipeline, where frequent Maps were published showing the progression of the current works and the boundaries associated with the construction. Such maps were reproduced quickly and efficiently through site surveying activities that utilised GNSS within the data capture phases of the project. This also touches on the area of asset management and replication of as-builds' to document and manage the constructed assets (infrastructure).

Finally, the benefits of operational efficiency, sustainability and management over the entire project lifecycle are a major positive for the construction sector. Such benefits lead to better public perception of the industry and more scope for future approvals on works.

Appendix D References

ACIL Allen. (2008). *The value of spatial information in the Australian Economy.* Malbourne: CRC Spatial Information

Allen Consulting Group 2007, *The Economic Benefits of Making GPSnet Available to Victorian Agriculture*, Report to the Department of Sustainability and Environment, July.

Allen Consulting Group 2008, *Economic Benefits of high resolution positioning services*, Report to the Department of Sustainability and Environment, November.

Brian S. Fisher and Sabine Schnittger, 2012, *Autonomous and Remote Operation Technologies in the Mining Industry: Benefits and Costs*, BAE Report 12.1, Canberra, February

Guðbrandur Steinþórsson, 2008, *GPS Machine guidance in construction equipment,* Haskolin Reykavik University – School of Science and Engineering

Lateral Economics. (January 2009). *Nation Building for the Information Age.* Canberra: Lateral Economics

McNab, K.L. and Garcia-Vasquez , M. 2011. *Autonomous and remote operation technologies in Australian mining.* Prepared for CSIRO Minerals Down Under Flagship, Minerals Futures Cluster Collaboration, by the Centre for Social Responsibility in Mining, Sustainable Minerals Institute, The University of Queensland. Brisbane.

Seymour C. 2005, *Applications for GNSS on Shovels and Excavators*, http://www.infomine.com/publications/docs/Seymour2005.pdf, Accessed 5 August 2008.

Smith, Steve. Anglin, Tania. Harrison, Karen 2010, *Sugarloaf – A Pipe in Time*, Melbourne Water.

ACIL Allen. (2008). *The value of spatial information in the Australian Economy.* Malbourne: CRC Spatial Information.

Lateral Economics. (January 2009). *Nation Building for the Information Age.* Canberra: Lateral Economics.

UN Office for Outer Space Affairs. (2010). *Current and Planned Global and Regional Navigational Satellite Syetems and Satellite-based Augmentation Systems.* New York: United Nations.

Websites

CRC Construction Innovation, *Visualising Construction through Automation,* http://www.construction-innovation.info/index9b99.html?id=365, accessed 10th October 2012.

Melbourne Water, *Sugarloaf pipeline project,* http://www.melbournewater.com.au/content/water_storages/water_supply/water_distribution/sugarloaf_pipeline.asp, accessed 5th October 2012.

Machine Guidance,*http://www.machineguidance.com.au/*, accessed 10th October 2012.

ACIL ALLEN CONSULTING

Precise positioning services in the Utilities Sector

An estimate of the economic and social benefits of the use of augmented positioning services in the Utilities S With advances in communications, technology, greater satellite coverage from space

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

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Executive Summary

The utilities sector includes electricity, gas and water services. Efficient delivery of these services is important for competitively priced services to residential, commercial and industrial customers as well as ensuring efficient and sustainable use of resources.

Augmented GNSS contributes significantly to the productivity and competitiveness of the utilities sector. It is used in conjunction with geographic information systems to construct, monitor and manage network assets, manage faults, maintain systems and forecast demand. This produces lower development costs and more efficient asset management.

Output from the utilities sector is estimated to have been between $50 million and $81 million higher as a result of the use of augmented GNSS in asset management and maintenance. With further adoption in asset mapping and control systems, this could increase to between $173 million and $305 million by 2020.

Further improvements in productivity are expected as the technology is adopted more widely across industry and as more innovative applications emerge (see Appendix B).

With advances in GNSS coverage, and its integration with other sensors, the use of precise positioning for asset management should improve rapidly and allow much greater flexibility in monitoring of assets within complex environments, particularly underground services. The primary benefit of having more accurate spatial records of such assets is greater efficiency for fault finding and maintenance as well as lower costs for new construction in their viscinity.

These estimates have been derived from industry consultation, case studies (Appendix A), publicly available economic information and technical advice from experts in precise positioning applications. The figures reflect current industry positions which, combined with estimates of adoption of existing and new technologies, provide insight into the projected productivity benefits that could be realised by 2020.

An important benefit of improved asset management is less disruption to the community, business and the environment when work is undertaken on maintenance and replacement of these services.

Key Findings

- Precision positioning plays a critical role in supporting asset management for utilities.
  - Augmented GNSS is more cost effective for capturing location data necessary in the planning and construction phase of infrastructure development.

  - It is emerging as an important enabling technology for subsequent management of infrastructure assets.
- To aid this management, precise positioning is required to accurately map networks and other assets in conjunction with geographic information systems - augmented GNSS provides this precision.
- More generally precise positioning has contributed savings operating and maintenance costs associated with the development and management of the utility assets.
- Realisation of further savings will depend on future levels of adoption, further innovation in related spatial technologies and expansion of GNSS augmentation services.
- New technologies are likely to include improved GNSS services and receivers, mobile mapping technologies, remote sensing techniques and advanced surveying and setting out systems (see case studies in Appendix A).
- Compatibility between future augmentation services will also be required for these outcomes to be realised.

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. This report addresses the utilities sector.

The utilities sector includes electricity, gas and water services that are generally regarded as essential services supporting the community, business and industry. The industry value added of the sector was around $36 billion in 2010-11 representing around 2.5 per cent of GDP at that time.

The purpose of this report is to provide an understanding of the economic and social benefits of precise positioning information within the aviation 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 Utilities use of Precise Positioning

2.1 The utilities sector

The utilities industry comprises organisations that create manage and maintain infrastructure to provide essential services such as electricity, gas and water.

Utilities are generally capital intensive and efficient management or their infrastructure, plant and equipment is one of the most critical functions of their operation. Information on the location, status and operation of these assets is fundamental to this process.

GIS systems, and related position data, have become important enabling technologies in the design, construction and management of the infrastructure assets of utilities.

2.2 Design and construction

Before any investment in infrastructure can take place designers must consider mapping and natural and built environment factors to plan optimal routes and in some cases prepare environmental impact statements. GIS systems are now the norm in planning and design. Surveying technologies increasingly rely on precise GNSS to produce route plans and prepare the base maps on which the designers base their route decisions.

Designers often have to take into account the location of other infrastructure assets especially underground power lines and gas, water and sewerage pipe systems. Precise GNSS is becoming important in mapping and locating existing infrastructure especially that located underground.

The case studies included at Appendix A show how the capture of location data using remote sensing techniques and precise GNSS provides accurate records of the location of existing assets. These records can be drawn on when planning and designing extensions and expansions to the existing systems. The approaches taken by Ergon Energy and Energex to mapping and recording their electricity distribution assets, is an illustration of this approach.

The ROAMES being developed by Ergon Energy for example is a remote sensing system that will accurately locate and describe the electricity distribution assets. The system will be enhanced in the future though the use of a state wide CORS network to provide precise GNSS positioning date for input into the system.

Ergon Energy expects to realise savings of up to $44 million over five years from this system. This represents a saving in staff and materials of around 2 per cent.

2.3 Asset Management

Asset management is probably one of the main areas of benefit from the use of GIS systems and precise positioning. The term asset management applied to any system that is used to monitor and maintain the assets of an organisation. In the utilities sector this generally refers to management of assets such as transmission and distribution systems, dams, reservoirs, power stations, water treatment plants and control systems.

Intelligent management decisions enable more efficient control of energy and water supplies, improved service to customers, higher levels of supply reliability, improved asset lifetime and reduced maintenance costs, which all contribute to significant increases to the productivity and operating margins of utilities.

Using precise GNSS to assist with the task mapping the location has multiple benefits for utilities. Asset management techniques employ precise positioning along with a number of other remote sensing and reporting systems to monitor operating status, control systems, identify faults and plan and manage maintenance.

More accurate knowledge of the spatial relationship between infrastructure assets and the environment generally enables more intelligent asset management (and ultimately efficient) decisions.

Accuracy requirements vary from asset to asset. Data capture at the centimetre level has value in making more informed decisions about the condition and operational status of infrastructure assets such as the location of underground cables of distribution pipes. Accuracy requirements for above ground assets can be less demanding but decisions still benefit from the greater accuracy and reliability of augmented GNSS.

The case study on underground detection and data management discussed at Sections A.4 and A.5 in Appendix A demonstrate the value of being able to accurately locate assets for both design and construction has reduced the chance of damage to other infrastructure reducing maintenance costs and work- around tasks.

The case study of the use of precise positioning combined with high rate sensors in New South Wales Roads and Maintenance Services (section A.3 of Appendix A) is used to improve asset performance, asset maintenance and asset valuation. This is achieved through the rapid capture of geo-referenced images of road networks across the State.

2.3.1 Benefits

The main benefit of locating assets via precise positioning techniques to the utilities sector are in the ability to spatially reference the relative position of different assets and their immediate environment. Whilst not all applications of asset management require precise positioning at the cm level, different asset classes (such as underground assets) benefit substantially from the cm level positioning accuracy. This is demonstrated in a number of the cases studies as per Appendix A.

These benefits may include:

- Data that is collected within a GIS environment is spatially correct and can be viewed in its correct position relative to other spatially correct data
  - for example underground services with respect to property boundaries.
- Assets can be managed more effectively relating to their immediate environments
  - For example monitoring vegetation in proximity to power lines. Such as with the ROAMES and Ergon Energy case studies.
- Accurate calculations can be made of distances and offsets between structures.
- An accurate location of assets within the GIS environment can be determined on the ground by setting out the coordinates using precise GNSS technology.
  - this is of major importance for locating underground services that no longer have any evidence of position visible on the ground
  - the need for greater coordination in the management of underground assets increases each year as service networks expand and increase.
- Time spent locating services and waste involved in uncovering assets is minimised.
- Data can be shared between organisations electronically in digital format via email or the internet.

Utilities that engage GNSS for asset mapping, such as Energex, have been reported as able to achieve operational cost savings in asset mapping in the order of 5-10 per cent (PwC 2008). Our research discussed in the case studies confirms this finding.

For example the ROAMES case study shows that Ergon Energy expects to realise savings of up to $44 million over five years. These savings will be realised through the elimination of some tasks currently required in management of assets by providing more accurate assessment of asset status enabling faster and more precise maintenance and repair actions. This represents a saving in total staff and materials cost of around 2 per cent across all of Ergon Energy's activities (Ergon Energy, 2012).

The use of such asset management tools has increased over the past five years as more utilities install spatially enabled asset management systems which largely comprise off the shelf Geographic Information Systems (as shown in Appendix A). Industry research suggests that adoption of such technologies (and utilising precise positioning techniques) has increased effectiveness or asset management and improved productivity of utility operations. Generally 5 cm accuracy will be required for these purposes.

Productivity improvements vary across different utility sectors with the largest direct benefit of precise positioning being realised in electricity distribution and underground services. However this is likely to spread to gas and water services as more commercial systems become available and existing control systems (SCADA) are upgraded and extended.

2.4 Underground Services

Precise location of underground assets is highly valuable and precise GNSS is fundamental supporting technology to GIS asset management systems. This saves time and money in both service delivery and lifecycle management. This is particularly relevant to managing large pipe networks that require excavation of bitumen, concrete and other hard surfaces.

Whilst it is impossible to fully detect every service asset that has been previously placed underground, it is an endeavour of new management strategies to now correctly spatially locate services as they are constructed, thus mitigating the risks of unexpectedly uncovering these services at later dates. Precise GNSS offers the most flexible approach for providing accurate spatial information to as construct surveys and as such is being widely used across many existing utility operations.

The use of precise GNSS along with GIS and remote sensing technologies is demonstrated in the case study on underground service detection and data management at section A.4 of Appendix A. Accurate information on the location of underground infrastructure is of benefit to both the owners of the infrastructure and to others who wish to locate additional infrastructure in the viscinity of existing assets. The benefits discussed below have been drawn from this case study and the NBN case study at section A.5.

2.4.1 Benefits

Location of assets, as has been demonstrated through the above ground features of energy and road networks is imperative to effective decision making and maintenance options. Linking positional information into the realm of underground services will provide numerous similar benefits.

The benefits of precise positioning in this context include:

- mitigating potential damage of the service
- fast data capture (through GNSS)
- cost effective management
- Data collected can be integrated directly to existing GIS platforms.
- The position on the grade can be set-out using the coordinates previously recorded (which will assist in protecting the underground cabling from accidental damage), prior to construction or digging, compared to current methods of radar detection or vacuum which aren't cost effective.
- Data can be shared between organisations in digital format
- security and protection of assets.

A subset area of asset management of particular interest to not only utilities (in their overall quest for better management of assets), but the broader community, is that of underground services. It is imperative to both the security and maintenance of these assets, that disruption to these services is avoided. However with limited spatial awareness of their locations, damage and disruption are often unavoidable as other construction, civil or service providers look to uncover these areas.

The estimated productivity benefits include:

- reduced maintenance costs through damage and repair to assets
- reduced costs from other agencies in evaluation of area of works (i.e. less requirement for service detection when correct spatial asset management has been applied correctly)
- improved health and safety through accurate mark outs of service depths
- reduced disruption to services from damage or disturbance resulting in higher usage of service.

3 Future Applications and Developments

With advances in communications, technology, greater satellite coverage from space based and ground based augmentation resulting in wider coverage of augmented GNSS, utility companies will have access to even more advanced positioning techniques that can provide more accurate and comprehensive spatial information across their vast network of assets in a timely and affordable manner.

For example, the use of Unmanned Aerial Vehicles (UAV) as a new technology to rapidly and repeatedly capture high volumes of asset information is currently being trialled amongst power utilities. Advances in the applications of this technology are highly dependent on supporting precision GNSS infrastructure.

In addition, with endeavours such as the NBN leading the way, there will be a renewed focus on locating underground assets as they are placed, thus building comprehensive knowledge of underground services which currently don't exist. The combined use of radio frequency identification (RFID) markers and augmented GNSSS is becoming more prevalent in the industry. This technique more accurately locates and then records underground assets (refer appendix A-4) and is emerging as a key technology in the quest for more comprehensive underground asset databases.

4 Economic Impacts

Economic impacts in the utilities 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 and product development.

Productivity as reported by the Australian Bureau of Statistics has been decreasing in the utilities sector over the last ten years (ABS, 2012). According to research undertaken for the Productivity Commission, this is likely to be attributable to significant investment in upgrading supply security over this period[1] . This has offset other improvements in efficiency that have been observed in our case studies and research. With pressure on the utilities to reduce price increases, productivity improvement is a high priority for this sector.

This report focusses on the direct productivity benefits from the use of precise GNSS technologies. We have estimated productivity improvements from evidence collected from the case studies, our estimates of current and future levels of adoption, published research and reports and from interviews with industry participants.

[1] The Productivity Commission has produced research suggesting that the downturn in productivity in the capital intensive industries can be attributed in part to the relatively high level of capital investment in recent years (Zhao, November 2012) (Top, 2008).

4.1.1 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.

Table 1 **Productivity estimates for 2012**

Enterprise	Assumptions	Direct impact (Low)	Direct impact (High
Asset Management	Above Ground Asset management only Approximate 10-15% productivity benefit realised by Energy Utility providers for above ground assets (i.e. power lines) Less direct impact for utility providers with services located underground. Based on adoption rates between 1 and 40 per cent.	0.010%	0.0.020%
Underground Service Detection	Less direct realised benefit due to the obvious difficulties locating existing underground assets. New assets being constructed and positioned underground are being more effectively managed given the increased capacity to directly locate for service and maintenance. Based on adoption rates between 1 and 20 per cent.	0.018%	0.035%
Council Level	Greater capacity to acquire information on above ground assets. Extrapolated from estimates made in 2008 and updated with results of research and ROAMES case study	0.053%	0.080%

Note: Productivity impacts are accumulated from 1995

Data source: SKM research, case studies, industry consultations.

Table 2 **Productivity estimates for 2020**

Enterprise	Assumptions	Direct impact (Low)	Direct impact (High)
Asset Management	Above Ground Asset management only Based on adoption rates between 40 and 80 per cent.	0.015%	0.040%
Underground Service Detection	Greater sophistication in the visualisation and location of extensive undercover asset networks (i.e. Pipelines) Based on adoption rates between 1 and 20 per cent.	0.141%	0.211%
Council Level	Greater ability to locate existing assets. Augmented positioning options will further the ability of GNSS to more effectively map multiple classes of assets. Extrapolated from estimates provided from Allen Consulting group 2008	0.107%	0.160%

Data source: Case studies, interviews and literature review.

These accumulated productivity impacts are translated into industry wide impacts and summarised in Table 3.

Table 3 **Productivity estimates**

	Low estimate	High estimate
	Productivity on costs	Productivity on costss
2012	0.018% utilities 0.005% local govt.	0.135% utilities 0.008% local govt.
2020	0.0.262% utilities 0.011% local govt.	0.0.411% utilities 0.016% local govt.

Data source: ACIL Allen and SKM research *(ABS, 2013)*, *(ABS, 2013)*

4.1.2 Impact on sector output

The productivity impacts summarised in Table 3 were used as inputs to ACIL Allen's Computable General Equilibrium (CGE) model, Tasman Global[2], to estimate the impact 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[3].

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

Table 4 **Impacts on output**

		Low case	High case	Low case	High case
		2012	**2012**	**2020**	**2020**
Increase in output	$ million	50	81	173	305
Percentage of total output		0.1%	0.2%	0.3%	0.5%

Note:
Data source: ACIL Allen modelling

The table shows that output in the sector is estimated to have been between $50 million and $81 million higher in 2012 as a result of the use and application of augmented GNSS. This represents 0.1 per cent and 0.2 per cent of total output for the sector.

Output is projected to be between $173 million and $305 million higher by 2020. This represents 0.3 per cent and 0.5 per cent of total output for the sector. .

The higher outcomes in 2020 assume that adoption levels will more than double from a relatively low base now. With advances in communications, technology and with wider coverage of augmented GNSS in the future, utility companies are well placed to access advanced positioning techniques that can provide more accurate and comprehensive spatial information across their networks.

[2] See overview report for a full description of the CGE modelling approach,

[3] Note that the productivity shocks for other sectors discussed in this report were also entered into the model at the same time.

With pressure from regulators to reduce the infrastructure costs, utilities could benefit greatly from the efficiency improvements canvassed in this report.

Adoption levels are likely to benefit from further integration of augmented GNSS with sensors and other systems for fast data capture and processing. The utilities sector is generally active in researching and trialling new applications. This is a positive for further adoption.

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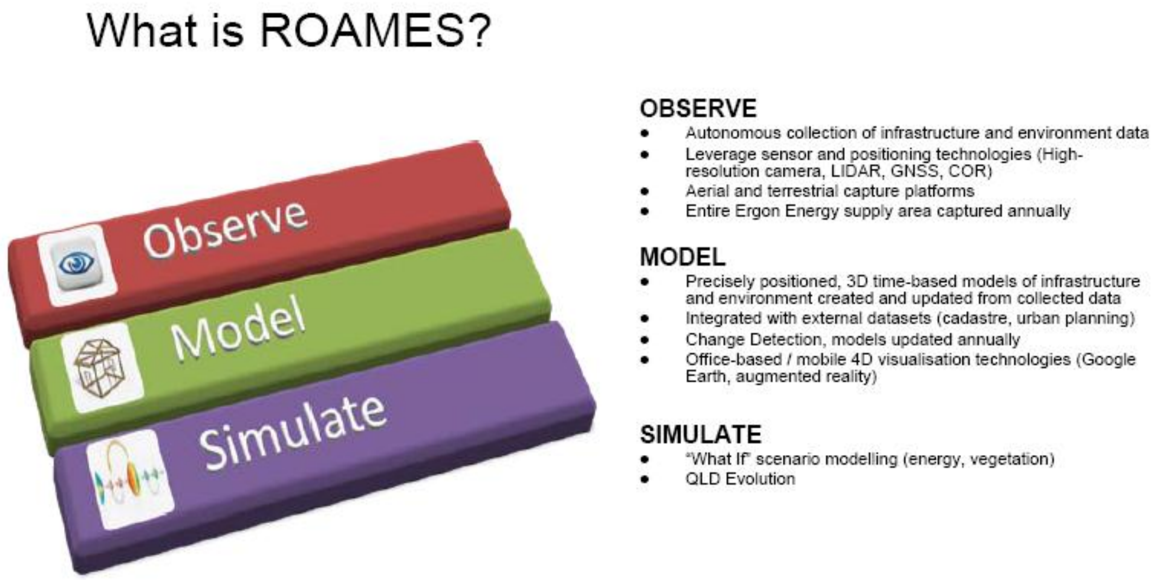
Appendix A Case Studies

A.1 Remote Observation Automated Modelling Economic Simulation (ROAMES)

This case study was provided by Ergon Energy, a Brisbane based electricity retail and distribution companies. Ergon Energy is an electricity retailer to homes and businesses in regional Queensland. It also maintains the regional Queensland electricity network.

Ergon Energy has implemented a spatially enabled remote sensing system to manage their extensive area (over 150,000km covering 97% of Queensland) of existing assets. Existing assets equate to over 8.7 billion dollars and are used to service over 680,000 Queenslanders. Thus any small improvement in management of both asset and surrounding environment can potentially save millions if not billions over the greater asset lifecycle.

Figure 1 **Remote Observation Automated Modelling Economic Simulation (ROAMES)**



1.

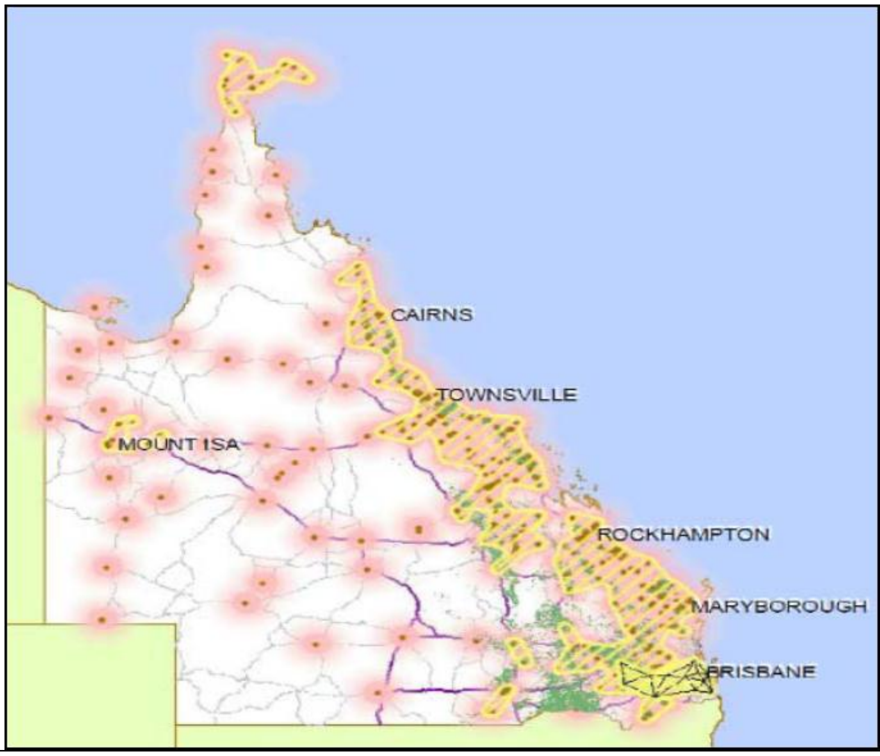
Data source: The Ergon ROAMES project – Department of Natural Resources and Mines

Remote Observation Automated Modelling Economic Simulation (ROAMES) comprises specifically modified aircraft fitted with either photographic or LIDAR distance measurement equipment. Such aircraft and then deployed over the expanses of the asset network to observe both infrastructure and surrounding environment. Information is then used to simulate both economic and environmental impacts on the asset network.

The system aims to locate assets (power poles, power lines and conductors, vegetation, buildings and terrain) at the centimetre accuracy level and relate (spatially) to existing environmental features to help determine asset condition and manage appropriately. This concept has been supported in collaboration with other government agencies and organisations at both the state and national level given the significant other uses that the collected data may also facilitate.

To support the high accuracy associated with the data capture tasks, it has been proposed that up to 600 new reference stations (CORS) be established state wide. The establishment of such an extensive reference network is seen as the most economically viable way to support this ambitious program and ensure the widest possible uptake of supported activities associated with the program.

Figure 2 **Shaded areas represent CORS coverage (less than 70km between stations) to support ROAMES positioning requirements**



Data source: The Ergon ROAMES project – Department of Natural Resources and Mines

Using GNSS to assist with the task of asset mapping has the potential to benefit the utilities sector across both private and government levels. Asset management techniques employ GNSS amongst a combination of other sensors to evaluate aspects such as conditioning and numbers.

As it stands, Ergon currently uses limited positioning technology as it provides little value given the underlying limitations of Queensland spatial infrastructure (e.g. inaccuracies in cadastre/DCDB, inaccuracies in asset locations, limited reference stations); these limitations are particularly exaggerated in the predominately rural/remote business operations of Ergon.

Whilst initial investment costs are high, the benefits of such wide scale asset management could deliver several economic benefits. Ergon Energy is currently working with the Department of Environment and Resource Management (DERM) on opportunities to use ROAMES imagery to maintain accurate cadastres (Ergon 2012). There are also numerous other benefits to all members of industry if the data from such infrastructure is made publicly available.

ROAMES is Ergon's strategic response that will enable the changes and adoption of precise positioning, however it is not just about augmenting Ergon's existing business processes with positioning technology, but rather re-thinking the paradigm (e.g. removing a task altogether) given not only positioning infrastructure but rich spatial models. Both of these provide the value proposition that ROAMES is promoting.

Ergon Energy expects to realise savings of up to $44 million over five years. This represents a saving in staff and materials of around 2 per cent.

A.2 Energex

In addition to Ergon Energy and their more advanced approach to wide area asset management, many other energy providers are utilising GNSS positioning amongst more refined tasks. Energex (Qld), utilise GNSS technology in a mobile mapping sense, amongst its management tasks for approximately 50,000 km of overhead and underground power lines and cables.

A significant issue for Energex has been compiling data bases that link their customers' location in relation to their networks. In the past there has been no dynamic link between the businesses customer database and their network maps, so that in managing their address systems assumptions, had to be made as to which part of the network serviced a specific address.

An indication of the extent of the mismatch was evident during storm events when the connection between customers addresses and the network was found to be only 38% accurate. As a result, service technicians were slower to respond to service calls, due to technicians going out to incorrect locations and failing to find the on-the-ground source of a problem quickly.

Error in the customer systems included wrong or badly managed addresses, missing or duplicated addresses.

Overall, efficiency improvements in Energex's business have come from improved integration of operations with spatial information, facilitated by greater positioning techniques. In the absence of GIS and GNSS, it would be necessary to revert to the service standards of the 1980s.

The approximate productivity benefit realised from the use of precise positioning GNSS asset mapping was estimated at 10% in 2008 (Allen Consulting 2008).

It is our view from examining the ROAMES case study and from industry consultations that the adoption and hence overall productivity benefits have increased since that estimate was made.

A.3 Infrastructure Asset Management

This case study was provided by the New South Wales Roads and Maritime Services.

Asset management is not necessarily restricted to the utility domain and must be recognised as a much broader concept that can be integrated amongst other industry sectors such as construction, civil engineering and transport. A prime example of asset management utilising GNSS combined with other high rate sensors, is the use of rapid capture geo-reference imaging amongst the Roads and Maritime Services (RMS) authority, to provide road conditioning and geometry reports on the extensive road networks throughout the state.

Rapid data capture for road condition and assessment (management and usage) via vehicle mounted geo-referencing systems, incorporate high rate GNSS data to supply the key spatial elements for image geo-referencing. This supports accurate interpolation of spatial features at the decimetre level.

Crucial to the operation and data capture is the reliability and timing of the GNSS data to ensure suitable accuracies are met. Traditionally, asset information has been referenced to the chainage of the road (which is sufficient for many purposes) however, with the availability of coordinate information, asset data can be linked directly into spatially enabled platforms such as GIS to give greater usage across multiple departments.

Figure 3 **An example of a mounted mobile geo-referenced image capture device**

Data source: Roads and Maritime Services (NSW)

A.3.1 Benefits

Precise positioning integration amongst rapid asset capture systems, such as the georeferenced imagery systems discussed above, ultimately allow large amounts of environment and asset information to be captured across vast networks of coverage.

- Data collected can be integrated effectively amongst spatially enabled platforms (GIS).
- reduced cost in re-locating assets
- reduced costs in mapping the assets
- More informed maintenance and management decisions can be made regarding the asset and upkeep of existing environment (for example, vegetation clearance from power poles).
- improved Asset performance
- more accurate asset valuation
- Datasets can support alternative opportunities, such as data collated as part of ROAMES supporting the maintenance of an accurate property cadastre.

A.3.2 Productivity Estimates

Effective management of large networks of assets is invaluable to the overall bottom line of utility companies. Intelligent management decisions enable greater distribution of service, improved service to customers (via decreased disruptions to service), improved asset lifetime and reduced maintenance costs, which all contribute to significant increases to the operating margins of the utility company.

Utilities that engage GNSS for asset mapping, such as Energex, have typically been able to achieve cost savings to operational costs of asset mapping in the order of 5-10 per cent.

More elaborate asset management concepts such as ROAMES, expect to realise savings of up to $44 million over five years.

A.4 Underground Service Detection and Data Management

This case study draws on information from NBN Co, Dial Before You Dig and SKM.

A subset area of asset management of particular interest to not only utility companies (in their overall quest for better management of assets), but the broader community, is that of underground services. It is imperative to both the security and maintenance of these assets, that disruption to these services are avoided, however with limited spatial awareness of their locations, damage and disruption are often unavoidable as other construction, civil or service providers look to uncover these areas.

As there is currently minimal survey accurate information for the layout and network of existing underground services (assets) across the country, there are a number of inherent risks transferred to the community as new development seeks to utilise and construct in the same areas where these services exist. Current methods of service detection require the incorporation and compilation of publicly available 'Dial Before You Dig' information, underground service proving through radar detection methods or NDD (Non-destructive digging), and/or survey pickup of radar detection points at ground level or over the proven exposed location.

Through these current methods, there are a range of costs and approvals required to carry out further underground work. Costs of such developments requiring the exposure of underground services can include surveyors, service locators, and excavators through to the costs of approval of dig/excavation permits. Even with such significant costs there are limitations as to the effectiveness of service detection and damage, disruption and injury are often experienced due to the uncovering of unknown assets during construction and development works.

Precise knowledge of underground asset location is also beneficial to the host and can result in large efficiency improvements in locating and servicing asset (increasing both service delivery and lifecycle). This is particularly relevant to utilities who manage large pipe networks that require excavation of bitumen, concrete and other hard surfaces given the costs associated in first detecting, then uncovering the asset of interest.

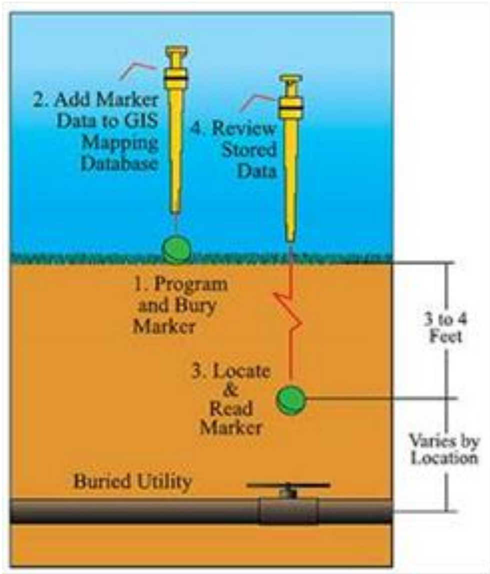
Whilst it is impossible to fully detect every service asset that has been previously placed underground, it is an endeavour of new management strategies to now correctly spatially locate services as they are constructed or provide other detection means later on, thus mitigating the risks of unexpectedly uncovering these services at later dates. GNSS, as a wide coverage high precision positioning system offers the most flexible approach for providing accurate spatial information to as construct surveys and as such is being widely used across many existing utility operations.

RFID Markers (Radio Frequency Identification)

One emerging technology that is currently being implemented is the combination of RFID markers with spatial positioning to create asset underground identification.

- Allows underground and aboveground assets to be ‘tagged’ with radio markers. These have been in use in the USA since at least 2006
- Markers are placed during construction with locations recorded via GPS. They can be buried at various depths depending on marker model
- Field teams can then relocate assets using the RFID reader and average quality GPS. Naturally they can also be shown/managed via GIS interfaces
- Tags can also contain asset information (asset type, material, depth, date constructed etc) so field teams can relocate the specific pipe if multiple pipes and markers have been placed close to each other
- Cost is approximated currently at about $25-30 each – these last about 25 years and are environmentally friendly if destroyed. The RFID reader costs about $5000
- Other RFID markers include plastic tape with embedded RFID chips spaced every 2 metres, which can be rolled along the pipes prior to filling
- Pegs that can be embedded on the surface (such as underneath cat’s eyes along the road or drilled into power poles).

Figure 4 **An example of a mounted mobile geo-referenced image capture device**



Data source: Ultimate Positioning

A.5 National Broadband Network

This case study was supplied by NBN Co Limited

Information shown on the Australian Government National Broadband Network (NBN) website indicates that the national rollout of the new high speed broadband project represents the largest infrastructure development ever undertaken in this country (Mike Rayner 2012).

A major issue relating to the project and an unfortunate reoccurrence over the years within the communications industry is that there is very little emphasis placed on long term infrastructure security by providing accurate as built information for the installed (underground) services. Thus there have been vulnerabilities with existing infrastructure assets resulting in damage of cables from future civil or construction works.

Several proposals have been submitted to NBN Limited Co to reliably provide accurate spatial locations (and resulting datasets) for the communications infrastructure and ensure significant cost savings through better management and minimal future disruptions to services.

The field data capture, to locate in ground assets is facilitated by GNSS precise positioning, which provides instantaneous coordinate information to be directly integrated in asset management systems (typically GIS). This information is either captured by on-site surveyors or specialist mobile mapping operatives who are equipped with customised GNSS receivers that are connected to an appropriate correction service (either GBAS or SBAS).

Previous practices, reliant on diagrammatic details on DBYD plans combined with expensive, specialist location services are easily avoided through correct as-built survey plans as assets are constructed. The future savings of such practices are invaluable and with GNSS being readily available to accurately capture asset position as it is being laid many operators are mandating the process. This is constant, not only across utilities, but construction and civil projects as well.

The use of GNSS and GIS within the NBN project has not been fully implemented across the country and is often dictated by the approach of the local governing body (council). However, the ability to currently use positioning in such a manor provides an affordable means for all interested parties to locate underground fibre optic cable with a high degree of confidence and allow designers to ensure future works can be placed to avoid potential conflict with the cabling

A.5.1 Benefits

Location of assets, as has been demonstrated through the above ground features of energy and road networks is imperative to effective decision making and maintenance options. Linking positional information into the realm of underground services will provide numerous similar benefits.

The benefits of precise positioning in this context include:

- mitigating potential damage of the service
- fast data capture (through GNSS)
- cost effective management
- Data collected can be integrated directly to existing GIS platforms.
- The position on the grade can be set-out using the coordinates previously recorded (which will assist in protecting the underground cabling from accidental damage), prior to construction or digging, compared to current methods of radar detection or vacuum which aren't cost effective.
- Data can be shared between organisations in digital format
- Security and Protection of asset.

A.5.2 Productivity Estimation

The estimated productivity benefits include:

- reduced maintenance costs through damage and repair to assets
- reduced costs from other agencies in evaluation of area of works (i.e. less requirement for service detection when correct spatial asset management has been applied correctly)
- improved health and safety through accurate mark outs of service depths
- reduced disruption to services from damage or disturbance resulting in higher usage of service.

A.5.3 Adoption Costs

The adoption costs of implementing management systems for underground assets are hard to measure directly and vary from utility provider.

However, the costs associated with field data capture and reliable database updates are minimal given the advent of GNSS technologies.

Appendix B Adoption

Current levels of precise position adoption amongst utility providers is limited to above ground assets only and in a vast majority of applications is further limited by the availability of accurate spatial data sets to support requirements of cm level positioning.

Adoption is largely centred on private energy providers whom manage wide expanses of infrastructure and assets such as power lines and poles.

B.1 Adoption Factors

Adoption is driven by a number of factors. More broadly speaking, the classic textbook reference by Rogers (1964) identified a five-step decision process involved in technology adoption and diffusion:

- Knowledge – potential adopter becomes aware of an innovation but has no particular opinion of it (this could be via advertising or through word-of-mouth)
- Persuasion – the potential adopter seeks further information to help form an attitude toward the innovation
- Decision – the potential adopter engages in activities that lead to a choice to adopt or reject the innovation (the process is internal to the person and can be difficult to measure empirically; however considerations of price and perceived usefulness/necessity will play into this decision)
- Implementation – the innovation is adopted and put into use (e.g., user installs geospatial data software or uses car navigation aids)
- Confirmation – person evaluates the results of an innovation-decision already made which may affect decisions such as whether to continue using the innovation or return to previous status quo (e.g. remove software or return car navigation aid).

Rogers also estimated the categories of adopters as being innovators (2.5 per cent), early adopters (13.5 per cent), early majority (34 per cent), late majority (34 per cent) and laggards (16 per cent. These reference figures are adopted for the current report, as they were based on and have been broadly corroborated by many case studies including those in the original contribution by Rogers.

B.1.1 Improvement in underlying spatial data

As was discovered during assessment of Ergon's ROAMES project, precise positioning is often limited in application due to the limitations of accuracy on other accompanying data sets that help comprise the greater information management and decision making. For example, with limitations on the accuracy of the digital cadastre and therefore definition of boundary, it is often a wasted exercise to locate typical utility assets at the cm level when the encompassing boundary data is only relevant at the metre level.

As improvements are made to larger spatial data sets and there accuracy refined, it is likely that the applications of precise positioning will grow in importance.

B.1.2 Technology Availability

As is the case with implementation of many new systems, adoption costs and availability of appropriate technology required to integrate precise positioning amongst encompassing management systems needs to be analysed compared to benefit. It is evident that utilities with above ground assets (largely electricity distributors) realise greater current benefit and as such are prepared to invest in the higher adoption costs associated with the use of technologies supported by precise positioning.

B.1.3 Underground Location and Detection

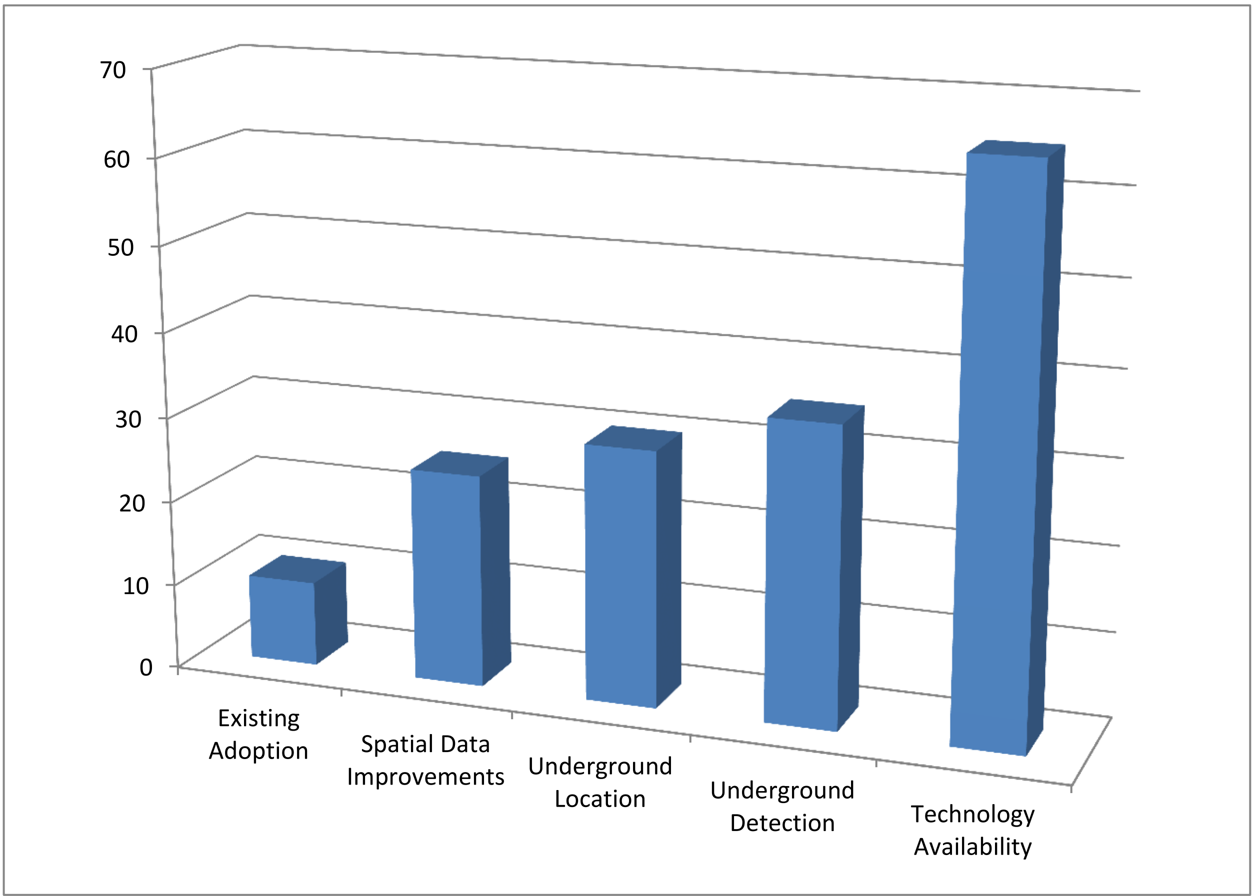
The major impediment for many utilities is of course the accurate location and detection of their extensive networks of underground assets. This is problematic as given the historical existence of many services such as water and sewerage which rely on vast networks of old pipe established over the last 50 + years, location of such assets is extremely difficult unless fully uncovered.

However, it is evident that attitudes are changing given the realisation of benefits of accurate spatial data. It is now becoming fundamental for such utility organisations to ensure accurate location of new assets as they are being constructed. With precise positioning being adopted amongst the creation of new assets, slowly, but surely, more complete asset management systems can be expected to be built up and replace the less reliable historical data sets.

Figure 5 sets out the influence that these factors are understood to have on levels of adoption.

Figure 5 below illustrates the estimated rise in adoption level (expressed in percentage) as various adoption factors are overcome through developments.

Figure 5 **Factors affecting levels of adoption**



Data source: SKM; Figure 5 represents the combined adoption of both above and below ground assets for the utility sector.

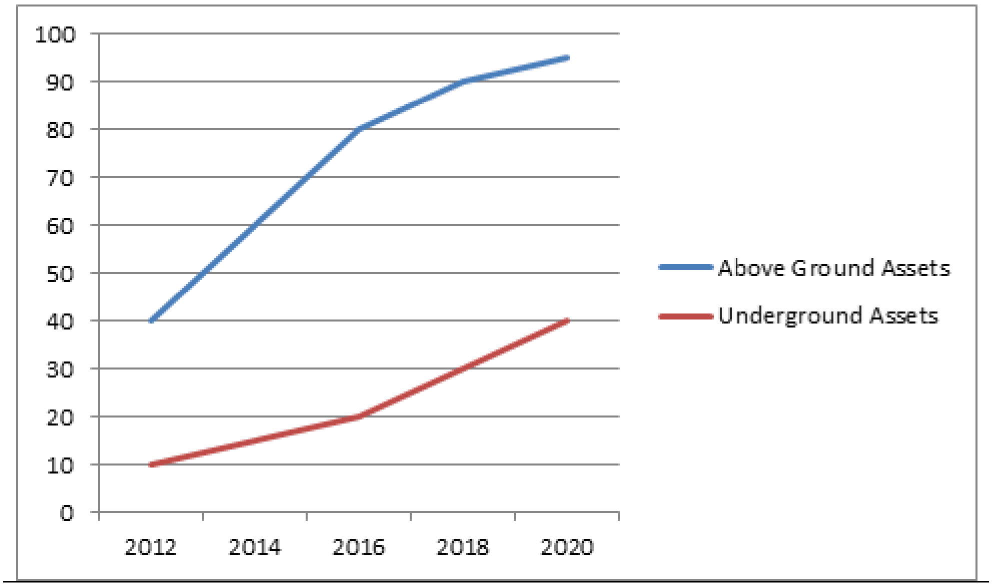
The adoption factors previously discussed and indicated within figure 8 are seen as the major impediments to adoption. As these are partially or fully overcome there will be a direct correspondence with utilities adoption of positioning systems and technologies. The estimates in Table 5 are speculative but an attempt to project the likely technological and structural advances in positioning adoption factors.

Table 5 **Estimated Timeframe for overcoming adoption factors – Utilities**

	Optimistic	Medium	Conservative
Spatial Data Improvements	2014	2018	2020
Underground Location	2014	2018	2025
Underground Detection	2018	2020	2025
Technology Availability	2014	2018	2025

The graph below (Figure 6) displays the likely increase in adoption of GNSS precise positioning technologies amongst the Utility sector. Two curves have been estimated based on the implementation of GNSS positioning amongst utility companies dealing with above and below ground assets.

Figure 6 **Adoption Curves**



B.1.4 Limiting Factors

Complete (100%) coverage via asset surveying techniques is often not possible and other techniques are often required to augment the process. GNSS has current limitations given the obstruction to satellite signals in certain areas of high vegetation, dense urbanisation and of course is limited to above ground assets only. As such, asset mapping across the sector incorporates a combination of techniques.

In addition emerging GNSS compliant alternative technologies such as Locata has the potential to extend precise GNSS into underground and metropolitan areas.

Also, given the nature of Australia's wide expanses and sparse population, there are currently difficulties associated with providing accurate centimetre level GNSS positioning at the real-time level for assets away from major population areas. This is simply due to the limitations of both communications and positional infrastructure in remote areas.

Whilst there is an increasing adoption of positioning and spatial approaches to asset management in the local government domain, these techniques are still in their relative infancy and existing systems seldom rely on centimetre level positioning due to the associated costs involved. It is a different story in the more commercial areas of utilities investment in asset management strategies utilising precise positioning is significantly higher and as such greater benefits are being realised.

Utilities with a large amount of existing infrastructure located underground have not readily adopted precise positioning for these in-ground assets and are often unable to reference spatial management techniques. Whilst efforts are made to build in spatial integrity to their existing asset management systems, given the restrictions in obtaining positions, these large networks remain at best speculative until uncovered and located directly. Ultimately, this results in higher maintenance and management costs to the utility provider.

Appendix C Social and Environmental

There are many positive implications through the applications of precise positioning amongst the utility sector. The most obvious benefit is that through correct management of large scale assets and infrastructure, utilities can better provide essential services to the greater community minimise disruptions and improve the quality of such services.

Environmental management surrounding the areas in which assets and infrastructure are contained is also a beneficial by-product of the collation of spatial data. Examples being the reduction in bushfire risk from ensuring appropriate clearances of powerlines and overheads from dense vegetation.

The concept of an augmented reality amongst full 3D visualisations of service networks is a concept being currently developed by several authorities with keen interest at local, state and federal levels. With improvements in the spatial collation of data as new services become constructed and old services relocated, advanced virtual environments will provide significant risk mitigation in the future by enabling a more interactive approach to understanding the complexity of service locations.

As has been demonstrated, through the ROAMES collaboration, improved asset management techniques engaged by private enterprises can have significant benefit to public authorities, the wider community and scientific endeavours. In fact, ROAMES as probably the most telling example of multi-purpose data use can support a vast array of environmental management objectives and further aids government in improving the capacity and accuracy of existing property boundary data (cadastre).

With great emphasis on sustainable practices, intelligent management through asset mapping, will only aid in the improvement of relationship between environment and asset network.

The generic exchange of data through certain authorities allows for more precision in planning and development stages of civil and future works. This avoids potentially hazardous situations around 'unknown' services and also avoids disruptions to fundamental services such as electricity, water and gas through damage to assets.

Appendix D References

ABS. (2012). *Productivity tables 5260.0.55.002*. Canberra: Australian Bureau of Statistics.

ABS. (2013). *5209.0.55.001 Australian National Accounts: Input-Output Tables - 2008-09*. Canberra: Australian Bureau of Statistics.

ABS. (2013). *81550DO002_201011 Australian Industry, 2010-11*. Canberra: Australian Bureau of Statistics.

Allen Consulting Group (2008), "Economic benefits of high resolution positioning services", Report

Darren Burns, Ergon ROAMES Project, Presentation

Ergon Energy. (2012). *Annual financial statements 2012*. Brisbane: Ergon Energy

Lateral Economics. (January 2009). *Nation Building for the Information Age*. Canberra: Lateral Economics.

Matt Higgins (2007) Delivering Precise Positioning Services in Regional Areas, Presented at IGNSS Symposium 2007, The University of New South Wales, Sydney, Australia, 4-6 December 2007.

Mike Rayner (2010), Submission to NBN Co Limited. Tweed Shire Council, NSW.

Steve Jacoby, Queensland Spatial Information Strategy, Presentation

Top, V. (2008). *Productivity in the Mining Industry, Measurement and Interpretation*. Canberra: Productivity Commission.

UN Office for Outer Space Affairs. (2010). *Current and Planned Global and Regional Navigational Satellite Syetems and Satellite-based Augmentation Systems*. New York: United Nations.

Zhao, S. (November 2012). An overview of Australia's peroductivity performance. *Productivity Perspective Conference* (pp. 6,7). Canberra: Productivity Commission

Precise positioning services in the surveying and land management sector

An estimate of the economic and social benefits of augmented positioning services in the surveying and land management sector

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

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Executive summary

The surveying and land management industry is a broad based, multi-disciplinary industry that is technologically advanced in its use of geospatial information systems. It operates in a wide range of sectors including, land development, mining engineering, property development and agriculture. Its activities also extend to hydrographic and geophysical surveys for the petroleum and mining sectors.

The position requirements of surveying are one of the most demanding of all of the land related activities. The cadastre, which is the spatial, textural and temporal record of property in Australia, requires centimetre accuracy. Similar levels of accuracy requirements arise for surveying and setting out of infrastructure and in land development.

Some surveying requirements are less demanding. Identification of points of interest or general location of property services and as built infrastructure may accept accuracies at the decimetre level. High levels of reliability and integrity are not as important for land surveying as in navigation applications. However high levels of reliability are required for offshore geophysical surveys where position is required in real time.

The surveying sector has been an early adopter of augmented GNSS. Surveyors use augmented GNSS in combination with other geospatial technologies to support accurate location of points in setting out engineering and other infrastructure. This saves significantly on labour costs reducing the number of surveyors and technical staff required on site.

In addition, position data that is embedded in digital mapping data supports the construction phase of projects and also supports maintenance and management of the infrastructure once built.

Important applications of augmented GNSS include regional surveys where the availability of control benchmarks is limited, engineering surveys, accurate sea level monitoring, infrastructure condition surveys and sub-divisions. Augmented GNSS is also actively used by the offshore sector in geophysical surveys.

Productivity improvements are significant in surveying and land management, ranging from about 20 per cent to 40 per cent in 2012 with a further 20 per cent likely by 2020.

Levels of adoption of augmented GNSS in the surveying sector are estimated to have been around 20 per cent in 2012. Future levels of adoption will depend on the availability of augmentation services across the country. They could be as high as 70 per cent or more by 2020 with further expansion of CORS networks for example.

The report estimates that in 2012, augmented GNSS had delivered cost savings to the surveying and land management sector of between $30 million and $45 million.

These savings are projected to increase to between $100 million to $150 million by 2020. These estimates are based on conservative assumptions on the rate of development of CORS networks.

Key findings

- Surveyors' use of augmented positioning tends towards the precise end of the spectrum, with precision at the centimetre level normally required. Whilst some surveying applications require lower precision, for example in the order of a decimetre, generally this precision requires specialist tools and techniques.
- The use of augmented GNSS is extensive in the surveying industry. Augmentation signals are provided through stand-alone RTK systems, CORS networks and space based augmentation services.
- Precise GNSS is already being applied in engineering and construction surveying and is finding further applications in regional surveys, infrastructure surveys, sea level monitoring, and sub-division and land development activities.
- The use of precise GNSS with innovations in geospatial technologies is delivering significant productivity gains for surveying of infrastructure. Tasks that traditionally took weeks can now be completed in days. These productivity gains also deliver economic benefits to a number of other sectors including the construction, mining and utilities sectors.
- Future levels of adoption will depend on the extension of augmentation services across the country. This could include both further developments of CORS networks as well as space based positioning services.
- Development of GNSS compatible positioning services for areas where GNSS cannot effectively penetrate such as indoors and underground could also contribute to expansion of the use of augmented GNSS by the surveying sector.

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 surveying and land management 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 surveying and land management sector

2.1 Background

The surveying and land management industry is a broad based, multi-disciplinary industry that is technologically advanced in its use of geospatial information systems. It operates in a wide range of sectors including, land development, mining engineering, property development and agriculture. Its activities also extend to hydrographic and geophysical surveys for the petroleum and mining sectors.

Surveying is the determination of the position of the boundaries of public or private land, including national and international boundaries and the registration of those lands with the appropriate authorities. The creation of titles relies on the output of surveyors in the subdivision process throughout Australia.

The provision of three dimensional spatial data services by surveyors is drawn on by developers, architects and engineers and forms the base data for conceptual and detail design for major infrastructure projects. Surveying also involves the construction phase and plays a role in the creation and formatting of spatially accurate and reliable 'as constructed' and asset management records.

Land management encompasses a broad range of activities including measurement, recording and laying out of land development. The advent of precise surveying technology has not removed the requirement for the application of land law and administration, however the manner in which ownership is depicted and recorded has the potential to change significantly with the emergence of geospatial data bases and precise positioning using techniques that include augmented GNSS.

Geophysical surveys are the foundation on which exploration programs for petroleum and minerals are planned and executed. Exploration is a high risk activity and information from such surveys is fundamental to the ongoing effectiveness of exploration programmes.

2.2 Surveying and land management sector's positioning requirements

The position requirements of surveying are one of the most demanding of all of the land related activities. For example the cadastre, which is the spatial, textural and temporal record of property in Australia, requires centimetre accuracy.

Topographic mapping and all surveying data relies on survey control marks that form the basis of Australia's geodetic framework. This framework provides the underlying control of position and elevation on which all surveying reference points are based. Fundamental geodetic data is required at the millimetre level and is determined from astronomical data, laser ranging stations and GNSS systems.

GNSS is widely used in the surveying sector. From a gradual take up during the 1990s, mainly amongst larger firms undertaking project control network surveys, most surveying firms now have GNSS capability. Further improvements in positioning technology can be expected to be rapidly adopted by the surveying industry.

Most surveying applications require higher precision than can be provided by stand-alone GNSS. Although surveyors are integral to the setup and maintenance of augmented GNSS in construction, mining and agriculture, there are some areas where surveyors require the integrated use of augmented GNSS with other geospatial tools to provide accurate reference frames for these activities.

The cadastre has been developed since Federation and accordingly it contains inherent inaccuracies of spatial definition in some areas. All Australian jurisdictions have regulated accuracy for cadastral surveys of between one to two centimetres. That accuracy can only be achieved with application of precision GNSS techniques. Typically these augmentations are provided through RTK[1], differential GPS or CORS[2] networks. Such approaches are not suitable in some circumstances, for example when structures or vegetation interfere with the augmentation signal.

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1 RTK means real time kinematics. RTK corrections can be delivered immediately to the receiver or are applied for post for applications such as surveying and mapping where immediate corrections are not required.

2 CORS refers to Continuously Operating Reference Stations

Surveyors both "identify" and "mark" property boundaries. For identification surveys, sometimes lower precision is appropriate such that single frequency or "asset grade" GNSS receivers can be employed. In this case DGPS[3] is used but the precision obtained, either via "real time" augmentation, or "post processed" is in the order of one metre in the horizontal plane[4].

As improvements to precise positioning emerge, it is likely that GNSS solutions will be increasingly used in cadastral surveying

3 Applications of augmented GNSS

Applications of augmented GNSS vary across the surveying and land management sector. Six case studies were used to illustrate different applications of augmented GNSS in the surveying and land management context. The case studies are referred to in the following sections while full details are provided at Appendix A.

3.1 Reference controls

Surveying depends on accurately positioned benchmarks for reference controls. The availability of control marks varies from jurisdiction to jurisdiction and from region to region. In some regions the availability of control benchmarks is limited and this can create problems for mapping and surveying.

Augmented GNSS can help overcome these problems by providing high level positioning accuracy over a wide area on which reference points can be based. This is illustrated in the first case study discussed at section A.1 of Appendix A.

In this example a CORS GNSS was used to overcome the lack of survey control marks for a photogrammetric survey on the Fleurieu Peninsula in South Australia. The survey was required to determine features from aerial photography such as road centre lines, kerb corners and fence posts over a wide area of the peninsula.

The necessary coverage was achieved using a GNSS system linked into a commercial CORS network. The augmented GNSS signals were used to provide greater flexibility in placing control in difficult locations where ground control did not exist.

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[3] Differential GPS – a form of augmented GNSS

[4] Real time augmentation relates to the situation when correction signals are broadcast via radio frequencies, such as for RTK GPS, or via Omnistar[4] corrections, or via CORS signals broadcast over a mobile phone network. Post processed means that data collected in the field is not corrected until returning to the office, where an internet connection is used to access base station data for software based "correction" of the raw data.

This application delivered significantly lower costs than would have arisen if conventional terrestrial survey techniques had been employed. It is difficult to envisage how this outcome would have been cost effective with conventional terrestrial surveying techniques. The wide coverage of the CORS network in the area enabled the necessary control points in a more economic and timely way.

It has been estimated that these techniques reduce the time required in the field for survey teams by around 75 per cent (Lorimer, 2007).

Such approaches would now be possible in regions of Australia where a CORS network is available. It would also be possible to do the same task with some space based commercial augmentation systems depending on the area to be surveyed and the accuracy of the service in that area.

Application of augmented GNSS services in this case delivers net savings in the cost of capturing survey market data in such areas. While the task would be theoretically feasible to do with conventional terrestrial surveys, the cost would probably make it uneconomic in most circumstances.

3.2 Engineering surveys

Engineering surveys often traverse routes in remote locations where the survey data is limited and where traditional land surveying would require time and personnel to travel the route measuring and recording route topography.

Detailed surveys of the route corridors for infrastructure such as pipelines and power lines require two centimetre accuracy and in the past this required a survey team to traverse the route. Most traditional survey teams require at least two surveying personnel which involves travel and accommodation costs as well as time to traverse the survey route. This can be both time consuming and expensive. With growing demands for infrastructure and rising costs, techniques are needed to undertake engineering surveys more efficiently and at lower costs. Augmented GNSS has been an enabling technology that reduces the number of days of professional and technical time required to undertake each project.

The use and application of augmented GNSS for the engineering surveys are illustrated in the second case study (see Attachment A). This describes a survey for a natural gas pipeline in Tasmania. In this project, real time and post processed GNSS positioning data was used to refine and prove up the route for the proposed pipeline networks that stretched from Bell Bay to Hobart in the south and Burnie in the north west. RTK GNSS was also used for set-out and completion of an as constructed survey. The as-constructed survey subsequently provided a data base for the pipeline operator to use for operations and maintenance once operational.

This approach resulted in significant improvements in the efficiency of site selection, route selection, construction and subsequent operation and maintenance of the network of gas transmission pipelines in Tasmania.

Recent developments

The pipeline was constructed in 2002-2004. Technology improvements since that time have resulted in further efficiencies in the use of augmented GNSS for engineering surveys. Detailed route surveys would now be more effectively performed with the availability of a commercial CORS network in Tasmania. Much of the primary control networks that were required in 2002 would not be needed today. The CORS network would be sufficient to cover the majority of the project footprint. RTK GNSS which requires multiple set up of base stations would no longer be required for many sections. River Crossings would still require some RTK set up and conventional survey techniques but the position corrections would be obtained from the CORS network.

If the pipeline were to be constructed today much of the route selection would be done by remote sensing. Lidar, Google and Nearmap imagery is also available for much of this work. Setout in 2012 would now be undertaken using machine control. Machine control is reliant on stable and reliable GNSS solutions that are enabled by the CORS networks. Such systems reduce the need for surveyors staking out designs by up to 90 per cent.

In the Queensland surveying market it was estimated in 2007 that productivity improvements of 30 per cent to 50 per cent were possible using the SunPOZ CORS network (Lorimer, 2007). It is clear that productivity benefits in excess of 50 per cent are possible through the use of augmented positioning with the CORS network.

In addition adoption rates are increasing. According to an SKM report prepared in 2010 into the viability of CORS in Tasmania,

> "Use of precision GNSS in earth moving in construction is expected to reach a market penetration of 60% by 2020, from a current penetration level of 15%. Again, market penetration is expected to increase with GNSS equipment becoming standard in earth moving equipment" (SKM, Feasibility Study - CORS Network Tasmania 2010).

Productivity impacts

Precise positioning technology has advanced to the stage where limited survey field work is required for engineering surveys where suitable augmentation signals are available. The expansion of the CORS networks and the use of laser guided trenching machines would now result in lower costs for completion of as constructed surveys. In this case, third party surveyor verification would not be required.

Looking forward five years, strengthening of CORS networks (together with associated mobile signal coverage) will continue to remove the reliance on surveyors for ground control and site setout. Improved communications will allow automatic updates to be sent from office to site, and fewer surveyors will be able to manage more projects simultaneously. This will be an important factor in addressing the current and projected skills shortage in surveying.

It is tempting to predict that, if the improvement in precise CORS networks continues for the next five years, as it has done for the last five, that take up for machine control will be virtually universal for projects of any significant size where CORS augmentation is available.

Productivity improvements of between 20 per cent and 40 per cent in staff and fuel costs are possible with a further 20 per cent improvement by 2020. The latter improvement would depend on the extension of augmentation services more widely in Australia. This could be either a CORS network or a space based system depending on the accuracy in regional areas.

3.3 Monitoring sea level rise

Sea level rise is a potential consequence of global warming. It threatens coastal communities and has been a focus of concern at all levels of government in Australia in recent years.

Records of tide levels are of considerable national and international importance for future research into sea level rise. Measurement of sea level rise requires stable reference points with accurate elevation data to provide reliable time series on which estimates of sea level rise can be made. Land movement at tide gauge stations must be measured accurately if useful movements in sea levels are to be obtained. An accurate time series of land movement is required for adjustments to be made to tide gauge observations.

Accuracies of less than 1 mm are required for this purpose. GNSS augmented by signals from a CORS network are ideal to provide accurate and continuous measurement of land movement at tide gauge stations. Recent studies have shown that CORS GNSS is able to provide vertical land motion monitoring with an accuracy of better than 1 mm per year (Janssen, 2013).

Tide gauge records have been augmented with GNSS CORS technology in New South Wales. Compared to traditional monitoring methods based on terrestrial surveying techniques, the use of CORS GNSS technology is reported to offer significant improvements in the measurement of land movements at tide gauges. This is described in the case study at section A.3 in Appendix A.

GNSS CORS offers continuous monitoring within a global reference frame. Precision and accuracy with a CORS GNSS is improving with time and can be homogenous across all sites. Finally labour costs are lower as the CORS GNSS reporting is automated whereas periodic terrestrial surveying requires at least two surveying staff per survey. In addition traditional terrestrial monitoring is periodic whereas the CORS GNSS provides continuous reporting.

It is difficult to estimate the savings from utilising the CORS network in such applications. Periodic measurement with terrestrial methods would not produce a continuous record so to some extent the use of CORS GNSS for this purpose has no feasible alternative approach.

Net savings would be the difference between the periodic costs of terrestrial surveys and the marginal cost of locating CORS stations close to tide gauges. While these savings are important the benefits of better data are significant in terms of informing research into and understanding of potential sea level rises on the east coast of Australia.

3.4 Infrastructure surveys

Surveying of existing linear infrastructure often requires surveys to be undertaken over long distances and in relatively remote areas. Surveying of road conditions for example is critical for assessment of maintenance needs and planning of maintenance activities but can involve long survey distances and low level survey data. Traditional terrestrial survey techniques can be time consuming and costly in such circumstances.

Augmented GNSS when linked to other geospatial technologies can significantly lower the time required and costs of infrastructure surveys and produce more useful results in some cases. This is illustrated in the case study of the Tarkine Road evaluation project discussed in section A.4 of Appendix A.

Road management authorities frequently require an evaluation of the condition of roads for assessment of maintenance needs or for consideration of upgrades to address changing user demands. The Tarkine Road in Tasmania is an example. This road required upgrading and sealing in order to form part of a tourist loop road. As part of the evaluation the road designers needed data to analyse areas that would require realignment and sight distance assessment.

A conventional survey would have been prohibitively expensive, so an innovative "Structure from Motion" technique was used. A camera was attached to a vehicle which drove the route. The resulting imagery was correlated with mapping grade GNSS to calibrate a digital model of the road from the imagery. However, the mapping grade GNSS was found to create positioning errors that propagated through the length of the road and required considerable reworking by the designers to correct these errors.

Augmented GNSS would have overcome these problems. If a CORS network had been available at the time of the survey, RTK solutions could have been employed that would have increased the accuracy and eliminate the propagation errors. Greater availability of CORS networks would facilitate greater innovation in data collection techniques. Some existing techniques are expected to be replaced by a combination of image capture and accurate positioning resulting in significant productivity improvements in road surveying and design.

Productivity improvements estimated from such techniques are estimated to be 25 per cent less time in the field and 50 per cent less office time required. In addition accuracy of the data collected is expected to be up to 80 per cent higher with a CORS network. These improvements are considered to be representative for applications in all jurisdictions where equivalent networks are available.

3.5 Land Management and subdivisions

A significant part of the work of the surveying industry is in laying out subdivisions for new housing developments as well as rural and industrial area subdivisions. Traditionally, such surveys were carried out with electronic theodolites, or total stations, and required a minimum two person field party. This is because line of sight surveying requires stations to be occupied and traverses to be constructed linking up the various sections of the survey. Line of sight surveying is necessarily constrained by topography and vegetation. The more undulating the terrain and the denser the vegetation, the slower the progress of the survey, and consequently the greater the cost involved.

GNSS surveying is to a large degree unconstrained by these limitations. Vegetation is only an issue when the canopy is sufficiently dense to interfere with satellite signals. Topography is only an issue when intervening hills disrupt repeating radio signals. Additionally, most of the survey could be completed by a one person field party.

Traditional traversing can achieve between 800 metres and 2000 metres per day depending on the constraints earlier described. The case study of a rural sub-division examined in section A.6 at Appendix A demonstrates the savings that can be achieved with GNSS surveys.

For this project, it is estimated that an average of 1500 metres per day would have been required for a traditional terrestrial survey for a rural subdivision. With the aid of RTK GPS, this project achieved 4,544 metres per day. The time required for the survey was reduced from an estimated 15 days for a traditional technique to 4 days with RTK GNSS. This is equivalent to a productivity improvement of around 70 per cent.

With the extension of CORS networks such productivity improvements would be possible more widely in Australia.

3.6 Geophysical surveying

The oil and gas sector relies on geophysical surveys in the early stages of exploration. The types of exploration activities that are predominantly supported by augmented GNSS are offshore seismic and bathymetric surveys which both contribute to the overall geophysical assessment of potential and existing hydrocarbon deposits[5].

Precise position is typically required at the decimetre level utilising Differential GPS (DGPS) corrections delivered by satellite communications as opposed to the centimetre level positioning associated with RTK. Such corrections are typically supplied via private operators via satellite communications to resolve positional ambiguity.

Whilst DGPS is the primary service utilised for 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.

Woodside Petroleum has estimated that around 10 per cent of exploration expenditure can be lost due to downtime which is in part attributable to poor navigation data and inefficiencies in steering survey vessels. Woodside invests around $100 million per year in such activities implying an annual saving of around $10 million a year. Augmented GNSS signals contribute to these savings (see Section A.7 of Appendix A).

3.7 Emerging developments

3.7.1 Extension of augmented GNSSS coverage

Expansion of CORS networks along with further development in the accuracy of space based augmentation services will contribute to further adoption of the techniques described in this report and hence the productivity gains that are potentially achievable.

Another potential development is the emergence of non-satellite dependent augmented GNSS systems to fill in gaps where GNSS cannot penetrate reliably. Such areas are where buildings or canopy cover interferes with the satellite signal and indoors, in tunnels and in underground mines. Developments such as the Locata localised GNSS compatible positioning technology could extend the coverage of precise positioning[6].

Future levels of adoption of augmented GNSS will be driven by the availability and cost of augmentation signals across Australia.

5 Sources: Woodside

6 The Locata system is an Australian developed localised GNSS system that uses local transmitters to create an augmented GNSS signal. It is not dependent on satellites and can be used in urban areas and underground where satellite signals are either unreliable or not available.

3.7.2 Augmented reality

Augmented reality is an emerging innovation where accurate positioning combined with digital mapping and simulation technologies is revolutionising planning and design of infrastructure.

Augmented reality (AR) combines real and virtual information in real time or near real time in a 3 dimensional environment. In the world of surveying, AR is an emerging technology that is linked to other professional areas such as town planning, mine planning, asset management, emergency management and urban renewal.

With the advent of GNSS enabled mobile devices such as Smart Phones and Tablets, AR is on the cusp of becoming a standard tool for surveying and planning professionals. AR has uses both indoor and outdoor, so whilst augmented GNSS signals such as Locata have limited use for conventional surveying, they will be critical to the take up of AR systems indoors.

For real time use, AR relies on positioning techniques, principally at present from GNSS enabled devices. Since autonomous GNSS positions in hand held devices are generally of lower precision than those from devices capable of receiving corrected signals, the uses, at present, of AR are limited to imprecise, or indicative, applications only.

If, however, autonomous positioning improves, the usefulness of AR for precise applications will correspondingly increase. For example, if a developer wishes to show a local authority the likely impact of a proposed development, the proposed building can be loaded into a tablet device, and used at the site to view the building from any location, to a precision consistent with GPS accuracy on the tablet. This is suitably accurate for this application.

However, if a local authority asset manager wishes to locate buried assets with AR enabled glasses, then the GNSS positioning in the glasses needs to be of higher precision than currently available. Decimetre precision is required for the accurate location of buried services.

Therefore, for major design projects the use of augmented GNSS is likely to significantly improve the useability of AR systems. The surveying industry is yet to adopt AR as a working tool. However, the industry links with the construction and development sector where uptake is considered to be more likely and widespread. As in the machine control examples, the role of the surveyor will be in data management, quality assurance and reporting.

AR has the capacity to replace paper plans, and when linked to a single server, can provide real time updates on works in progress by combining data received from, for example, laser scanners attached to the front of construction machinery. These techniques are already in use in the gaming sector.

Augmented reality has the potential to significantly improve the efficiency and effectiveness of the surveying and design process for land management and infrastructure development. A summary of the rates of adoption is provided in Appendix A.

4 Adoption rates and productivity

4.1 Estimates of rates of adoption

In order to estimate the economic benefits that have been delivered by augmented GNSS systems in Australia we used case studies of applications in the surveying and land management sectors to provide a verifiable estimate of productivity impacts. The findings of these case studies, combined with estimates of levels of adoption across the industry were used to estimate sector wide productivity and cost savings. The assumed levels of adoption were based on wider industry consultations and the knowledge held by the consulting team.

The rate of adoption of augmented GNSS is likely to depend on a number of factors including:

- the rate of roll out of the CORS network
- integration of augmented positioning with other technological innovations such as structure from motion techniques and development of augmented reality technologies.

In a study prepared in 2008, Allen Consulting estimated that the adoption of precise GNSS by the surveying sector was around 8 per cent in 2008[7]. Since that time the CORS network has been expanded in Victoria, New South Wales, Queensland, South Australia and Tasmania. Our interviews with the industry suggest that since that time the adoption level had increased to around 20 per cent by 2012. Future adoption will depend on the further extension of CORS networks and other augmentation systems.

We have assumed a continued roll out of CORS and rapid development of complementary technologies for the high scenario and a slower roll out of CORS and technological development for the low scenario. Our assessment is that adoption could reach 90 per cent by 2020 with a full roll out of the CORS network in Australia and 70 per cent with a more restricted roll out. This concurs with an assessment made by SKM's 2010 study (SKM, 2010).

4.2 Productivity

Productivity improvements are significant in surveying and land management ranging from 20 per cent and 40 per cent in 2012 with a further 20 per cent by 2020.

[7] Allen Consulting Group, The Economic Benefits of Precise Positioning, November 2008

In addition, augmented reality has significant potential to improve the quality of planning and design of land and infrastructure developments through its potential as a 3 dimensional imagery that supports community consultation on design and planning, consultation between surveyor, engineer and architect and design decision making. This has not been included in the productivity assessments.

5 Economic impacts

In order to estimate the economic impacts of precise positioning we made allowance for the fact that without precise positioning the surveying industry had alternative but less efficient options including emerging laser and related technologies to undertake their tasks.

These estimates of costs savings were combined with estimates of rates of adoption in 2012 and 2020 to provide industry wide estimates of cost savings from the productivity improvements available from precise positioning.

5.1 Estimates of cost savings to the surveying and land management sector

Surveying is classified as under Professional, Scientific and Technical services in the Australian and New Zealand Standard Industry Classifications. There is no breakdown of the size of the surveying sector in industry statistics available from the Australian Bureau of Statistics. Based on earlier work we estimated that the surveying sector comprised around 1.3 per cent of this classification.

We assumed adoption rates of between 20 per cent and 30 per cent in 2012 and 40 per cent and 60 per cent by 2020. Savings from precise positioning use in survey work was assumed to be 30 per cent in 2012 and 50 per cent by 2020. Finally we assumed that the construction related surveys that we were addressing, represented about 50 per cent of the total market for surveying services. The estimates are summarised in Table 1.

Table 1 **Productivity improvements for surveying in the construction market**

	Assumptions			Low case	High case
		Productivity impact	Value $million	Productivity impact	Value $ million
2012	Cost savings of 30%. Adoption 20%-30%	3%	30	4.5%	45
2020	Cost savings of 50% Adoption 340%-60%	10%	100	15%	150

Note: Productivity ratios expressed as a percentage of cost savings.

Data source: ACIL Allen and Lester Franks research

The table shows that savings in labour costs of between $30 million and $45 million could have been realised by 2012 as a result of the use of precise GNSS for construction and mining surveys. With increased adoption and further development in technology, these savings could increase to between $100 million and $150 million by 2020.

The increased savings accruing in 2020 also assume that the availability of augmentation services is increased particularly the RTK and CORS networks which provide the levels of accuracy needed for most surveying tasks.

It should also be noted that significant economic benefits accrue to the construction, mining, transport and agriculture sectors from the use and application of augmented GNSS by the surveying sector. These aspects are discussed in the accompanying reports and in an overview report.

Appendix A Case studies

A.1 Photogrammetry survey control

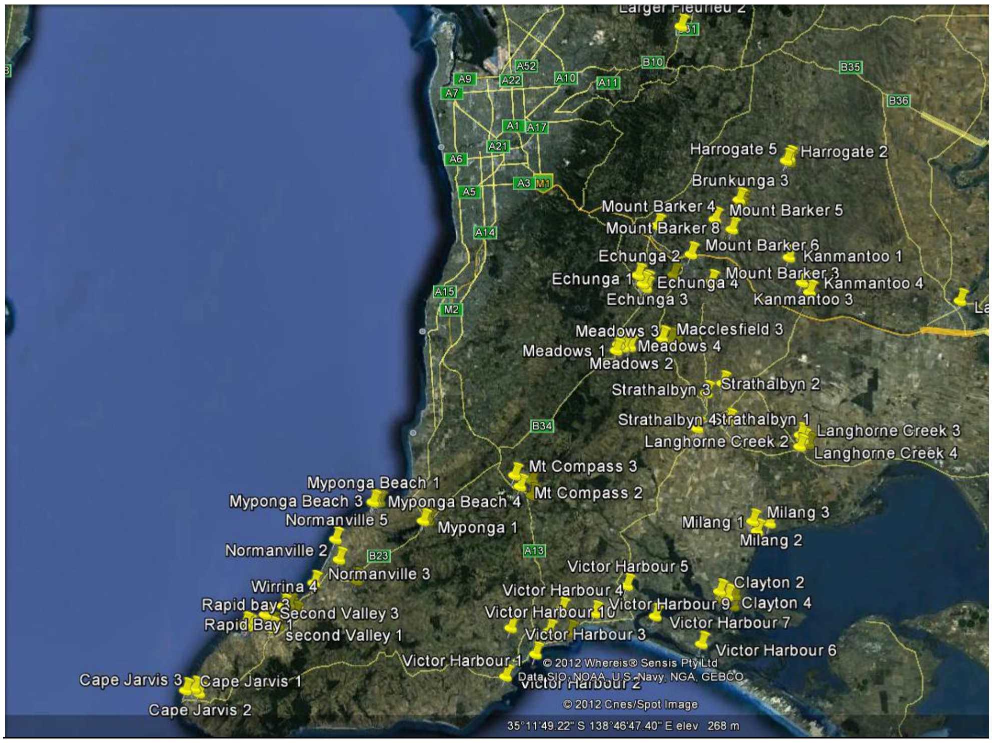
Sawley Lock Surveying, a survey firm based in Adelaide was engaged to provide photogrammetric control at locations on the Fleurieu Peninsula in South Australia. The locations generally centred on populated townships, most of which had 3rd order Tertiary Network survey marks to provide our MGA94 / AHD ground control.

The points required by the client, involved coordinating points that they could determine from aerial photography, features such as white lines on roads, kerb corners, fence posts and related infrastructure. The difficulty that presented to the surveyor was that not all areas had sufficient survey marks with 3rd order vertical control. The coverage across the wide survey area was variable with gaps in some areas of interest to the client.

To assist in covering the project more efficiently and with greater consistency an augmented GPS system from Position Partners was used that linked to the AllDayRTK broadcast CORS ground control network. This gave the surveyors greater mobility to place the required control in the difficult locations where little 3rd order control existed.

The coverage is shown in Figure 1.

Figure 1 **Coverage of ground control using CORS network**



Data source: Sawley Lock Surveyors

The use of the CORS network provided coverage that could only have been achieved with far more time consuming and expensive methods. It is difficult to envisage how this outcome could have been realistically achieved without the use of an augmented GNSS system.

A.2 Use of GNSS in engineering surveys

The Tasmanian Natural Gas Project involved the construction of a pipeline across Bass Strait from Victoria, to supply natural gas to Tasmania. In Tasmania, the project comprised approximately 430km of underground pipe from Bell Bay, north of Launceston, to Bridgewater, near Hobart, and across to Port Latta in the far north west. Construction for the project was completed in 2002.

This case study discusses the surveying requirements for the onshore Tasmanian component of the project as it was done, how it would be done now, and what the impact of improved precise positioning may be to a project of this nature in the years ahead to 2020.

A.2.1 How was the project undertaken in 2002?

The project comprised four surveying stages.

1. Route selection.

A trial one kilometre wide corridor was supplied by the proponents and preliminary route selection was made using state topographical series maps, and by synthesising from several sources:

- aerial photography
- 1:25,000 photomaps
- contours
- cadastre
- vegetation mapping
- geology
- land ownership records.

Surveyors then refined and proved the route in the field using mapping grade GPS capable of real time and post processed results.

2. Detailed survey of selected corridor.

Once the route was confirmed, the designers required a detailed survey of the proposed pipe centreline, and a 20 metre corridor at crossing features such as creeks and roads. Their accuracy requirement was 20 mm in all dimensions.

In order to ensure compliance, primary control marks were installed at 5 kilometre intervals throughout the corridor. Measurements were observed with dual frequency GPS over a period of three weeks.

The detailed survey was then undertaken using RTK GPS, with a base station calibrated to the control points transmitting corrected positions to the roving antenna in real time.

3. Setout

Following final design, setout was undertaken with RTK GPS. Setout information supplied to the contractor enabled trenching crews to control depth and alignment in an essentially manual environment.

4. As constructed survey

The proponent required every weld and every bend of the constructed pipe to be recorded by survey. Each weld had a reference bar code that was also recorded simultaneously.

This information was recorded with RTK GPS tied to the primary control network.

Since the pipeline traversed private as well as public lands, easements were required to be recorded as encumbrances on all affected Certificates of Title. In order to limit both the field and office components of this element, special instructions were approved by the Lands Titles Office and the Office of the Surveyor General permitting the utilisation of GPS equipment and a relaxation of the marking requirements of the survey regulations.

Nevertheless, all the easement processes were related back to and hinged on the primary control network and subsequent RTK GPS techniques.

A.2.2 How would the project be undertaken today?

1. Route selection

With the advent of improved aerial and satellite imagery, and the increased use of LIDAR technology, route selection for such a project requires far less ground survey. Approximately 95% of route selection for this project could now be completed using remote sensing techniques.

Of course, there is a significant cost to acquisition of LIDAR data (for example), however, consider that now there is recent Google and Nearmap imagery available for the cost of licensing and delivery. These avenues significantly enhance project planning. Also, LIDAR acquisition is increasingly being commissioned for multiple purposes during one mission, so as we move towards 2020 it can be reasonably assumed that more and more areas of the country will be accumulating terrain information.

2. Detailed survey of route

With the recent availability of CORS networks, also now just available in Tasmania, the creation of primary control networks which were required for this project could be avoided. The CORS coverage is presently sufficient to accommodate the entire project footprint.

Some infill control will always be required, however it is estimated that approximately 60% of the control network would no longer be required.

Therefore the detailed survey could be conducted utilising CORS solutions rather than RTK GPS, which requires the setting up of base stations and localised radio broadcast corrections.

In addition, if RTK is not required, the base station can be converted (switched over) to become another rover unit, thereby doubling productivity from a GPS kit, or halving the entry price depending on from which aspect this is examined. That is, only one rover is required with CORS, whereas a rover plus base is required for RTK.

Detailed survey at river and road crossings and for difficult terrain would be undertaken using RTK GPS, with position corrections obtained through the CORS network.

In addition, for the majority of the route, data available from LIDAR would be sufficient for design. However, designers are still in transition to their use of LIDAR data, partly due to concerns with accuracy. The planning and execution of LIDAR and aerial photography missions is heavily correlated with their usefulness for design.

For example, it is possible deliver terrain model products from aerial surveys that almost match the accuracy of ground based surveys. However the design of the flights and the associated ground control requirements are critical. A route selection series of rectified images is not the same as a fully controlled series of design images.

A further point to note is that the usefulness of CORS systems is significantly dependent upon the coverage of mobile phone signals, since this is the prime source of correction signal delivery. Therefore it is apparent that the densification and enhancement of CORS networks relies on cooperation with other agencies and technology suppliers, and commercial entities.

3. Setout

Today, setout would be undertaken using machine control. Surveyors are required onsite to set up the equipment, prepare and activate design data, and provide quality assurance and trouble shooting.

Machine control (MC) techniques depend upon stable and reliable GNSS solutions, and have developed rapidly since the advent of CORS networks. Whilst the hardware requires a significant initial outlay, MC systems reduce the need for surveyors staking our designs by up to 90%.

Similarly to the detailed survey elements of this project, productivity gains from CORS networks have a similar impact, in that a former RTK kit can be converted to two rovers for MC use.

There are limitations to the accuracy of GNSS CORS systems that still require infill solutions with traditional techniques. However those limitations would not significantly affect the execution of this pipeline project, if it was being conducted today.

According to a SKM report into the viability of CORS in Tasmania,

"Use of precision GNSS in earth moving in construction is expected to reach a market penetration of 60% by 2020, from a current penetration level of 15%. Again, market penetration is expected to increase with GNSS equipment becoming standard in earth moving equipment"

(Source, SKM, Feasibility Study - CORS Network Tasmania 2010).

4. As constructed survey

GNSS and laser guided trenching machines now record position of trenches as they are excavated. Therefore third party (surveyor) verification is mostly not required. The data can then be provided to a surveyor to produce as constructed plans.

So the increase in precise positioning available through MC systems greatly reduces the need for surveyors on site. Their role changes from construction setout to data management and quality assurance.

A.2.3 How will the availability of higher resolution positioning affect the methodology in the future?

As documented in this case study, precise positioning technology has already advanced to the stage where limited survey field work is required for such a project.

Looking forward five years, strengthening of CORS networks (together with associated mobile signal coverage) will continue to remove the reliance on surveyors for ground control and site setout.

Improved communications will allow automatic (on the fly) updates to be sent from the office to the site, and fewer surveyors will be able to manage more projects simultaneously. This will be an important factor in addressing the current and projected skills shortage in surveying.

It is tempting to predict that, if the improvement in precise CORS networks continues for the next five years, as it has done for the last five, that take up for machine control will be virtually universal for projects of any significant size.

A.2.4 Summary

The table below shows the estimated productivity improvements from improved precise positioning for several aspects of the project. The improvements are limited to the surveying components.

Table 2 **Estimates of productivity impacts #**

Item	2012	2020
Route selection	20% improvement	10% improvement
Detail Control	40% improvement	20% improvement
Detail survey	40% improvement	10% improvement
Setout	20% improvement	10% improvement
As constructed	20% improvement	10% improvement

Data source: *Lester Franks*

A.3 Monitoring sea level rise

Land and Property Information New South Wales has been installing CORS reference stations at or near tide gauge locations at locations on the New South Wales coast to better monitor land movements at tide gauges. The locations currently installed are Newcastle Port, Fort Denison in Sydney Harbour and at Port Kembla. This is a component of the broader installation of a wider CORS network in the state. To date around 120 stations have been installed in the network (see Figure 2).

These stations are being used to provide data on land movement in the vicinity of tide gauges to allow for land movement adjustments in the records of tidal movements over time. Such information is of national and international significance in providing time series of sea levels as data relevant to research into sea level rise as a consequence of global warming.

Figure 2 **NSW CORS network as at March 2013**

Data source: (Janssen, 2013)

Measurement of sea level rise requires high levels of accuracy and stable reference points. Land movement at tide gauge stations must be measured accurately if useful movements in sea levels are to be recorded by tide gauges. An accurate time series of land movement is required for adjustments to be made to tide gauge observations of land movement at tide gauge locations.

Accuracies of less than 1 mm are required for this purpose. GNSS augmented by signals from a CORS network are ideal for providing accurate and continuous measurement of land movement at tide gauge stations. Recent studies have shown that CORS GNSS is able to provide vertical land motion monitoring with an accuracy of better than 1 mm per year (Janssen, 2013).

Tide gauge records have been augmented with GNSS CORS technology in New South Wales. Compared to traditional monitoring methods based on terrestrial surveying techniques the use of CORS GNSS technology is reported to offer significant improvements in the measurement of land movements at tide gauges. For example GNSS CORS monitoring offers continuous monitoring within a global reference frame. Precision and accuracy with a CORS GNSS is improving with time and homogenous across all sites. Finally labour costs are lower as the CORS GNSS reporting is automated whereas periodic terrestrial surveying requires at least two surveying staff per survey.

Furthermore monitoring is only periodic with terrestrial methods whereas the CORS GNSS provides continuous reporting.

Table 3 **Comparison of land movement monitoring using traditional terrestrial survey methods and GNSS CORS**

Issue	Terrestrial methods	GNSS CORS techniques
Monitoring	Episodic	Continuous
Reference Frame	Local	Global
Land motion	Relative	Absolute
Data	Validated in house	Shared, validated by others
Precision	Generally fixed	Improving with time/algorithms
Accuracy	Survey specific	Homogenous across all sites
Data archiving	Manual and centralised	Electronic and distributed
Labour	Intensive	Automated
Intent and outcome	Limited	Multi user infrastructure
Alarms	Not applicable	Near real time

Data source: (Janssen, 2013)

A.4 Infrastructure surveys – Structure from Motion

The purpose of this project was to evaluate a 90 kilometre section of road from Arthur's River in the north west of Tasmania through the Tarkine forest.

The road is to form part of a tourist loop road and will require upgrade and sealing from its current gravel only status.

As part of the project evaluation, the designers required data to analyse which corners and bridge approaches did not have sufficient sight distance, which would subsequently influence re-alignment and vegetation removal.

A conventional survey of this distance (90 kilometres) would potentially be prohibitively expensive, and due to the remoteness of the site, existing imagery and photography was patchy and of questionable accuracy for the required purpose.

The company was commissioned to develop an alternative methodology to collect the necessary data.

A.4.1 How was the project undertaken?

A method of 'Structure from Motion' was developed.

Structure from Motion software uses algorithms to determine traceable points in video frames. These points are then triangulated between frames to produce a model of the road in an arbitrary 'pixel space' coordinate system. The model is then fixed to real world locations via alignment with simultaneously collected GPS data.

For this project, a commercially available 'GoPro' camera was attached to a vehicle, and correlated with a mapping grade GPS receiver such that the relationship between the two devices was known and could be incorporated into the solution.

The mapping grade (single frequency) GPS receiver was selected in this instance because it was likely to be less sensitive to obstructions such as canopy whilst still allowing analysis of collected data for precision. Static (motion free) observations were taken at selected intervals to increase accuracy.

RTK GPS, normally capable of achieving greater accuracy, could not be used as a control network did not exist, and the process of constantly moving the base station would have defeated the efficiencies hoped for.

In addition, CORS network solutions were not available due to remoteness and lack of mobile phone coverage.

After processing, it was found that positioning errors had propagated through the data due to the lower accuracy of the mapping grade GPS. Although the relative accuracy of sections of the road remained intact, the errors caused a misalignment with true absolute position that was significant.

Despite these deficiencies, the road designers were still able to use the data for analysis of sight distance, as the relative accuracy corner to corner was adequate.

So an innovative technique for a challenging project was completed in an environment where precise positioning techniques and augmentation could not presently be suitably employed.

A.4.2 How will the availability of higher resolution positioning affect the methodology in the future?

This project would have benefited from higher precision positioning technology.

If CORS was available, RTK solutions could have been employed and therefore significantly increased accuracy would be achievable. The propagation of errors from the GoPro camera could be properly accommodated by correlation to accurate positioning data.

The project team believes that the extension of high resolution positioning will facilitate increased innovation in data collection techniques. Some conventional techniques may be replaced by a combination of image capture and accurate positioning. This has correlations to mobile laser scanning however the intention of this project was to provide a very cost effective solution to a planning problem, rather than collect data sufficient for final design.

A.4.3 Summary of productivity impact

Table 4 **Estimates of productivity impacts on motion surveys**

Item	2020
Time Field	25%
Time office	50%
Accuracy	80%

Data source: *Lester Franks*

A.5 Augmented Reality

A.5.1 What is Augmented Reality?

Augmented reality (AR) can be considered as a live, direct or indirect, view of a physical, real-world environment whose elements are *augmented* by computer-generated sensory input such as sound, video, graphics or GPS data. Augmentation is conventionally in real-time and in semantic context with environmental elements. (Wikipedia).

Essentially AR combines real and virtual information, in real time or near real time, in a 3D environment.

In the world of surveying, AR is really an emerging technology, and is the link to other professional areas such as town planning, mine planning, asset management, emergency management and urban renewal.

With the advent of GPS enabled mobile devices such as Smart Phones and Tablets, AR is on the cusp of becoming a standard tool for surveying and planning professionals. Interestingly, AR has uses both indoor and outdoor, so whilst augmented GPS signals such as Locata have limited use for conventional surveying, they will be critical to the take up of AR systems.

Uses of Augmented Reality

The uses of augmented reality include:

- viewing ore body structures in the field
- visualising concealed assets both underground and encased within building structures
- directing emergency personnel within congested or obscured sites, for example, fire fighting within buildings
- visualising proposed developments on site – showing proponents and stakeholders impacts of building placement, shading, access
- In machine use for augmenting machine control so that operators have instant updates of works completed.

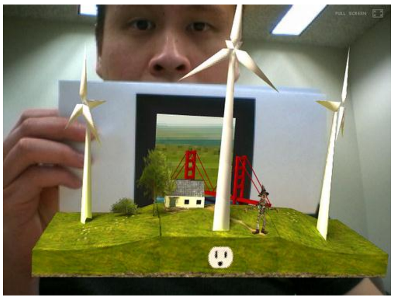


Image source: TBA – seeking acknowledgement.

For real time use, AR relies on positioning techniques, principally at present from GPS enabled devices. Since autonomous GPS positions in hand held devices are generally of lower precision than those from devices capable of receiving corrected signals, the uses of AR are limited to imprecise, or indicative, applications only.

If, however, autonomous positioning improves, the usefulness of AR for precise applications will correspondingly increase. For example, if a developer wishes to show a local authority the likely impact of a proposed town house on a vacant parcel, the proposed building can be loaded into a tablet device, and used at the site to view the building from any location, to a precision consistent with GPS accuracy on the tablet. This is suitably accurate for this application.

However, if a local authority asset manager wishes to locate buried assets with AR enabled glasses, then the GPS positioning in the glasses needs to be of higher precision than currently available. Decimetre precision is required for the accurate location of buried services.

Improvements in autonomous GNSS signals are therefore more important for AR than CORS systems, and the driver is likely to be the mass market consumer rather than specialist users. CORS systems are a specialist user system whereas AR is likely to be taken up on a much wider scale by unsophisticated users.

For internal applications, AR is heading towards the integration of multiple sensors such as Locata, WiFi, scanners, magnetic field sensors, gyroscopes, accelerometers and photogrammetry. A process known as SLAM (Simultaneous Location and Mapping) uses image recognition in a known environment to constantly update a users' location. The use of SLAM is heavily dependent on computing power as image processing is computationally intensive.

Levels of adoption

The surveying industry is yet to adopt AR as a working tool. However, the industry links with the construction and development sector where uptake is considered to be more likely and widespread. As in the machine control examples, the role of the surveyor will be in data management, quality assurance and reporting.

AR has the capacity to replace paper plans, and when linked to a single server, can provide real time updates on works in progress by combining data received from, for example, laser scanners attached to the front of construction machinery. These techniques are already in use in the gaming sector (e.g. the new Xbox).

A.5.2 Summary

Table 5 **Estimates of adoption**

Item	2012	2020
Knowledge within surveying industry	10%	60%
Knowledge within allied professions	20%	80%
Take up by surveying industry	1%	20%
Take up by allied professions	5%	50%

Data source: *Lester Franks*

A.6 Land Management – Okehampton Case Study

In 2008 Lester Franks undertook a large rural boundary re-arrangement, or subdivision for boundary adjustment. Since the properties involved were largely clear of vegetation except in pockets, RTK GPS was employed to complete the majority of the survey.

The property ”Okehampton” is situated adjacent to the town of Triabunna on the east coast of Tasmania. The combined area of the parcels to be treated was 1754 hectares. The property includes extensive frontage to the Tasman Sea.

Traditionally, such surveys were carried out with Electronic Theodolites, or Total Stations, and required a minimum two person field party. This is because line of sight surveying requires stations to be occupied and traverses to be constructed linking up the various sections of the survey. Line of sight surveying is necessarily constrained by topography and vegetation. The more undulating the terrain and the denser the vegetation, the slower the progress of the survey, and consequently the greater the cost involved.

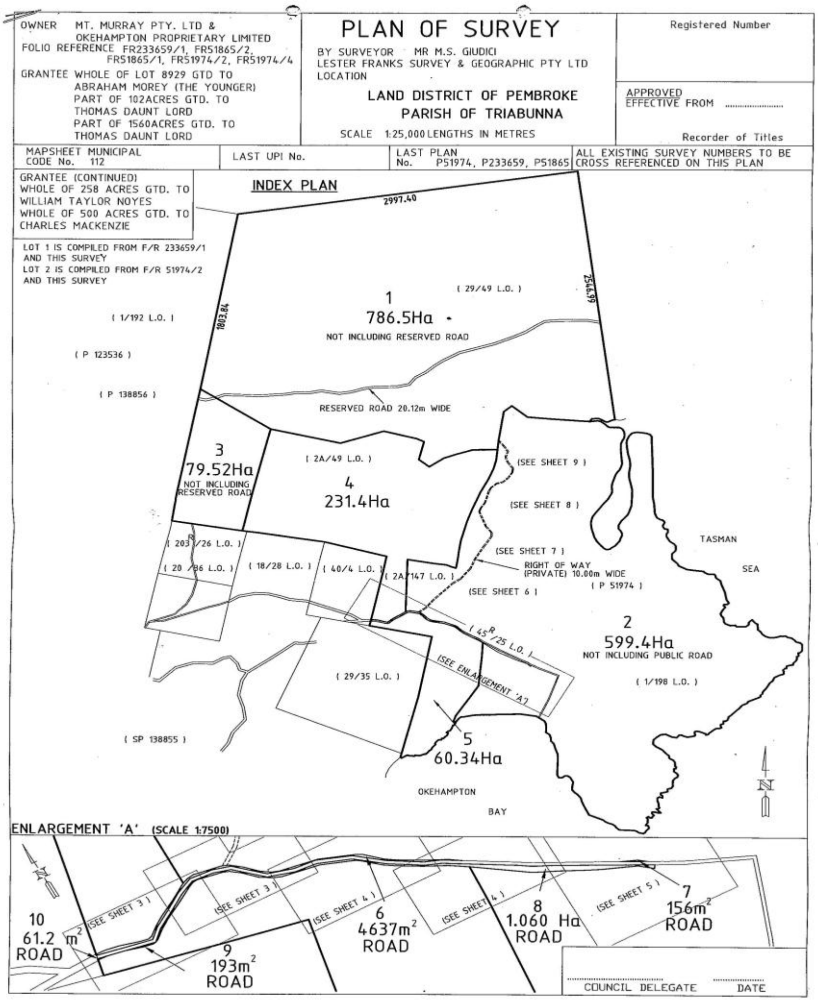
GNSS surveying is to a large degree unconstrained by these limitations. Vegetation is only an issue when the canopy is sufficiently dense to interfere with satellite signals. Topography is only an issue when intervening hills disrupt repeating radio signals.

Total distances surveyed in the project were 22770 metres. This was achieved in five field days, averaging 4554 metres per day, inclusive of placing pegs.

Traditional traversing can achieve between 800 metres and 2000 metres per day depending on the constraints earlier described. For this project, it is estimated that an average of 1500 metres per day could have been achieved, due to the largely open nature of the terrain. This implies a survey time of just over 15 field days. Additionally, most of the survey could be completed by a one person field party.

Savings introduced by GNSS in this instance were therefore approximately 66%. This translates into a significant cost saving for the client.

Figure 3 **Okehampton**



Data source: Lester Franks (2008

A.7 Geophysical surveys

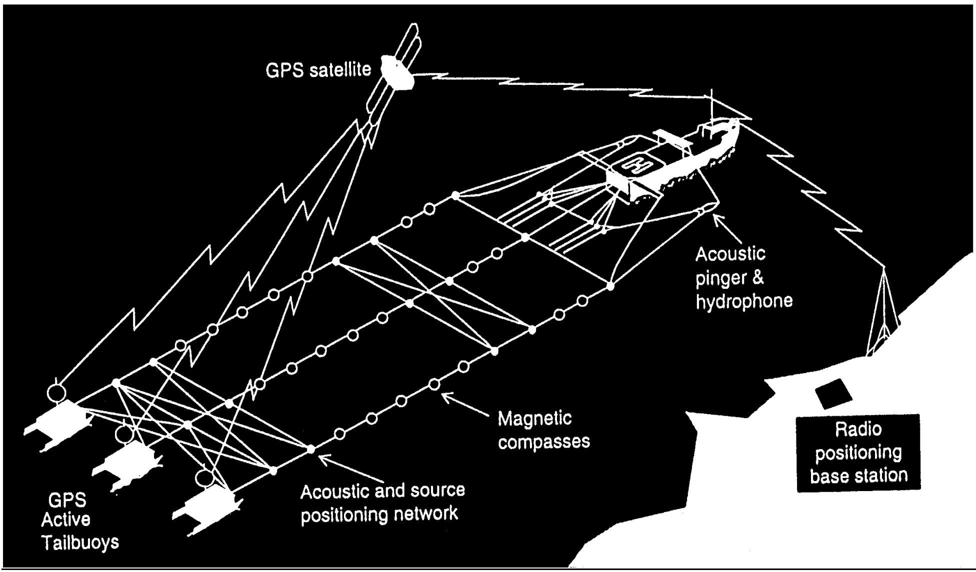
The oil and gas sector relies on geophysical surveys in the early stages of exploration requires Exploration activities that are predominantly supported by augmented GNSS are Seismic and Bathymetric surveys which both contribute to the overall geophysical assessment of potential and existing hydrocarbon deposits[8].

[8] Sources: Woodside

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.

Figure 4 **Navigation survey setup for an offshore Survey Vessel (Seismic) utilising DGPS correction**



Data source: 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 will be charged out in the vicinity of $700,000 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.7.1 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.7.2 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.

Appendix B Glossary of terms

Term	Definition
RTK	Real Time Kinematics
GPS	Global positioning system – the US Navstar system
CORS	Continuously Operating Reference Stations
GNSS	Global Navigational Satellite System
DGPS	Differential GPS – a form of augmented GNSS
DGNSS	Differential GNSS – this applies where greater accuracy and reliability is provided to the GNSS signal usually be transmitting a correction to the GNSS receiver. The correction is typically calculated using ground based reference stations such as in a CORS network

Precise positioning in the road transport sector

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

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

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Executive Summary

Road transport for this report includes passenger and freight transport, fleet management, transport logistics and the related support services that manage operations in the transport sector and road infrastructure support.

The transport and logistics sector was an early adopter of GNSS technology, using it to track vehicles, freight movement and is already widely adopted. In recent years the sector has experienced a growing need for greater accuracy, reliability, integrity and increased interoperability. These are required to support integration with complimentary intelligent systems to get greater efficiencies and competitiveness in logistics, reduce fuel consumption and maintain and service the infrastructure that supports it.

Areas where GNSS technologies have become important include:

- Fleet and Logistics Management — the precise position of fleet vehicles monitored in real time to assist in the management and optimisation of route selection, driver fatigue, fuel efficiency and timing.
- Container Management – Precise positioning has been adopted to automate and manage port container operations.
- Road Maintenance – Road authorities use positioning information to gather valuable information in the assessment of road corridors. Data capture is used for assessment of road geometry, condition and asset management.
- Intelligent Transport Systems (ITS) – a natural extension on fleet management, maintenance and tolling concepts.
- Direct Heavy Vehicle Charging – integration of reliable positioning systems to evaluate road usage and charge appropriately for heavy vehicles. Combined-service (heavy vehicle charging, fleet management, safety management).

Intelligent Transport Systems have already begun roll-out in Europe, USA and Japan. However, in regard to the specific precise positioning navigation aspects of C-ITS[1] Australia currently lacks the supporting positional infrastructure (via CORS[2] coverage) and the survey grade road base data to effectively facilitate certain functionalities at (largely) the 'where in lane' level of C-ITS. This can include functionalities such as those related to vehicle safety, which would require both precise positioning information and car sensor information to reliably make intelligent safety decisions based on the immediate road environment.

The Road Transport and Transport Storage and Handling sectors have jointly benefited from the use and application of augmented GNSS. Combined output from these sectors is estimated to have been between $154 million and $213

[1] See section 2.4

[2] Continuously Operating Reference Stations.

million higher in 2012 than it would otherwise have been without the benefit of augmented GNSS.

By 2020 combined output is projected to be between $534 million and $916 million higher than it would otherwise have been, as a result of greater use in cooperative intelligent transport systems and in freight and container management at ports and transfer nodes.

Realisation of these outcomes in 2020 depends on continued expansion of augmented GNSS services.

Key Findings

- Positioning across the transport sector has many varied applications including freight and logistics, vehicle charging, intelligent transportation systems and container management.
  - Existing freight and logistics systems typically don't require cm level positioning, however they do require the high reliability and integrity that can be provided by augmented GNSS.
  - Automation of freight facilities and transfer hubs have specific accuracy tolerances requiring reliable cm level precise positioning.
- Accuracy requirements vary depending on the application. However reliability, integrity and interoperability across multiple systems can be as important as positional accuracy in some circumstances.
- Significant improvements in productivity have been achieved from the use of augmented GNSS in transport applications. Further improvements are possible. Their realisation will depend on further development of applications as well as extension of augmented GNSS services.

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 transport 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 Transport use of Precise Positioning

2.1 The road transport sector

Road transport is critically important to the social, cultural and economic success of Australia, from our city centres to remote communities. With freight and passenger transport likely to almost double by 2020 Australia's transport system is facing many challenges including, congestion, accessibility and rising fuel prices.

A solution to this challenge is the adoption of new technologies that facilitate more efficient use of the current transport infrastructure and more effective output from available resources.

Whilst the road transport sector has been relatively slow to embrace new technologies relative to some other sectors, there has been a shift over the last several years towards more integrated, intelligent transport systems. This includes technologies such as in-vehicle telematics that can communicate with transport management systems, monitor vehicle movements and integrate them into a wider transport logistics.

These systems, supported by positioning technologies achieve commercial benefits by maximising the efficiency of freight logistics through higher productivity vehicles used in ways that are consistent with safety and environmental standards.

Generally the use of positioning across the road transport sector varies with each application. However there is an overarching requirement for positioning reliability, integrity and increasingly interoperability between different platforms.

Future directions of integrated positioning systems are envisaged through concepts such as heavy vehicle monitoring and intelligent access platforms (to be discussed below), which have requirements both for positioning accuracy, integrity and reliability.

These concepts point strongly towards the introduction of complete Intelligent Transport Systems (ITS) which may realise and combine a number of the applications described below within a precise positioning environment. This is driven by the need for greater efficiency in transport logistics to maintain competitiveness.

2.2 Logistics and Fleet Management

Positioning technology has been implemented in a number of applications to facilitate, manage and forecast the movement of freight, bulk materials handling and haulage.

There are numerous examples of standalone GNSS integration amongst logistic management systems, with information from this study being sourced from TOLL, Linfox and QUBE logistics.

Such positioning information generally only requires accuracies at the metre level and positional updates are not critically reliant on timing. Typically, under current operational conditions, these applications do not require GNSS augmentation at this point in time. However as discussed later in this report, provision of greater precision and integrity will facilitate further applications in managing fleets of trucks and in tracking movement of goods being transported. This is what augmented GNSS provides.

Benefits

The benefits of positioning across freight and logistics are estimated to be in accord with the following:

- reduction in fuel consumption, estimated at 10 per cent.
- 3 % increase in driver productivity from improved logistics management
- minimises idle time to ensure continuity of operations
- improved fleet efficiency (identifying areas of underperformance)
- more efficient time management and route optimisation

2.3 Direct Heavy Vehicle Charging

Road Transport Infrastructure is one of the only remaining public sector assets yet to undergo major economic reform, whilst there have been a number of steps taken to implement change comprehensive structural reform has not taken hold in the sector.

Moving to more direct heavy vehicle charging involves replacing the existing schemes with a variable usage charge based on the axle loading of each heavy vehicle and the distance and route (road type) of individual trips. This would provide charges that more closely reflect the costs incurred from heavy vehicle traffic. This would deliver benefits by encouraging:

- the use of more efficient routes by heavy vehicles where there is a choice available, as the charge for using a road is more directly attributed to the cost of a particular heavy vehicle trip
- a more efficient heavy vehicle fleet mix, as operators over time make vehicle choices based on minimising the total heavy vehicle charging costs of road use.

At present there a number of mechanisms being considered for collecting relevant data to support direct heavy vehicle charging. The favoured method is the use of in-vehicle (IVU) telematics linked to GNSS technology[3].

Whilst the accuracies associated for this application aren't required at the sub-metre level, there is significant emphasis on the reliability of service (and hence positioning service) to relay and record correct information to the system operators.

Such reliability will most likely require GNSS augmentation given the issues associated with poor satellite coverage in denser urban areas. The importance of accuracy in this area will depend, to some extent, on the nature of the location based charging and dynamic method adopted for data collection of variable parameters.

Benefits

The expected benefits from charging heavy vehicle behaviour include

- lower total heavy vehicle operating costs for a given freight task
- improvements in road safety from having fewer, more productive vehicles on the road
- avoided cost of road wear from more efficient use of the existing road network
- changes in vehicle operating costs from switching to larger, more productive vehicles, partially offset by potential increases in kilometres travelled by such vehicles
- potential fleet management operator benefits, from the use of information provided by in-vehicle units
- safety benefits from the use of in-vehicle technology, resulting in lower crash costs and reduced injuries and
- improved environmental outcomes from more intelligent management of road networks.

[3] Business Systems to Support Heavy Vehicle Charging – COAG Road Reform Plan October 2011

Overall, initiatives such as the COAG heavy vehicle reform suggest positive net benefits in the order of $5 billion to $7 billion over 30 years. The contribution of positioning systems to this net benefit would be speculative, however as a concept it leads into the development of intelligent transport systems which do have a precise positional requirement and it is likely that future systems will all be embedded amongst Cooperative Intelligent Transport Systems (see section 3.4 below).

Assuming a take-up of 8,400 vehicles, Intelligent Access Programs (refer Appendix A) are estimated to generate a net present value (that is, present value of benefits less costs) of $264.2 million over seven years (allowing for two implementation years) and a benefit cost ratio of 5.4. Across all applications, the authorities' net present value is estimated to be $80.9 million and the operators NPV $183.3 million. These results do not appear highly sensitive to assumptions about benefits and costs.

Net benefits will be realised through more direct road use charges with the introduction of distance-location charging methods (supported via GNSS) anticipated capturing a projected $6 billion across fleet wide introduction (COAG, 2011)

2.4 Cooperative Intelligent Transport Systems C-ITS

C-ITS facilitates the connection of road users to their road environment via the connection and exchange of real-time information about the road environment, such as

- vehicles, infrastructure, non-infrastructure features and other objects
- road and traffic conditions
- events
- threats and potential hazards.

The exact positioning requirements that have been broken down are as follows:

1. Road-Level Applications – Metre level positioning at approximately 1 sec (1 Hz)
2. Lane-Level Applications – Sub metre level positioning at approximately 1 Hz
3. Where-in-Lane Level Applications – Decimetre level positioning at 0.1 sec (10 Hz).

Currently, such ITS systems are being realized in Europe, Japan and USA where they have access to a Space Based Augmentation System that can fulfil the positioning requirements of the system. However, Australia does not currently possess such positioning augmentation levels and as such is currently not in a position to reliably support the implementation of ITS.

There is the inherent risk that without infrastructure development (be it at ground or space borne augmentation) that Australia will miss out on both the many environmental, safety and economic benefits that such systems support.

Benefits

There is considerable evidence collected from within Australia and abroad that ITS can produce reductions in accident rates and improvements in transport efficiencies (ACIL Tasman 2008). This reasoning for the safety improvements has been reinforced by information from the case studies discussed below. It is derived from improvement in understanding by the driver and the relationship between direct road environment information and current position.

Improvements to the efficiency of transport can also yield environmental benefits. For example, it is estimated that ITS will produce fuel savings of between 2% and 13% and reduce emissions by between 5% and 15% (Standing Committee on Transport and Regional Services, 2002).

Putting this in context, in 1998 Australia's transport sector contributed about 12% to the total of Australia's greenhouse gas emissions, with road transport accounting for 81% of these emissions. It is therefore estimated that the potential ITS reduction of road transport related emissions of 5-15% could reduce Australia's total greenhouse gas emissions by between 0.5% and 1.5%.

2.5 Container Terminal Management

The movement of containers is facilitated by large mobile straddles which are able to attach/detach containers (various straddles accommodate different container sizes) and transport them to a desired location. Of importance to effective operations is the locality of such containers as they are moved around the holding facilities. The typical accuracies required to effectively manage such operations are +/- 3 cm in the horizontal plane.

As such, precise GNSS is used to capture locality data of containers, referenced to a regularly updated site locality plan (facilitated via regular survey), at the loading points from the straddle.

The overall potential benefits of full site automation facilitated through precise positioning can be extrapolated from the Patricks estimate of $55 million per site, per year. Further benefits can be defined as (below);

- fuel and transport efficiency
- reduced machine wear and tear
- pavement / asphalt management
- improved safety (reduced collisions and transport related risks)
- reduced driver injuries due to remote straddle operation
- route optimisation
- reduction of labour through automation

- storage management
- fleet monitoring.

Such productivity benefits are currently being realised from existing automated and semi-automated sites across the country. It is estimated that fully automated facilities, such as those in place at Fisherman Island (Patricks), have reduced current staff levels by up to 50%. Sites operating under semi-automation have reduced levels of staff by up to 33% and have recorded mass savings in a number of key areas.

Previous to the adoption of GNSS as part of the container management process, hand-audits were conducted as part of the management process which required full site shutdowns and limited verification process. Inefficiencies associated with such practice added an additional 20-30% cost with overall processes.

On the basis of fuel costs estimated at 1000 litres per straddle per day (continuous operation), a perceived 30% reduction in fuel from smoother operation (as provided from estimates provided by Patricks) and controlled speeds puts an estimate of savings around 109,500 litres of fuel per Straddle per year, or an approximate saving of close to $200,000 per year at current diesel prices.

2.6 Future Applications and Developments

Advances in GNSS through both improved satellite coverage and augmentation will drive a number of transport related technologies within the coming decade. It is clear that positioning (at a standalone accuracy level) is already used as a logistics tool in a vast majority of major commercial operations, however with positioning improvements will come more advance applications and benefits.

The two primary examples of this future direction requiring centimetre level positioning is through automation (particularly relating to port and loading facilities) and the inevitable advent of C-ITS.

Telematics is the specific technological capacity to locate vehicles in space and time and is at the core of C-ITS. With the advances in positioning technology and its augmentation with supporting infrastructure, GNSS is becoming the primary form of navigation linked to telematics and is at the heart of current and future intelligent transport systems. Australian investment in C-ITS has been more than matched by advances internationally, however with appropriate infrastructure and system development, the expectation is that Australia will benefit greatly from implementation of such systems. The range of services being provided or explored include both domestic and commercial vehicular operations including:

- in-vehicle navigation
- stolen vehicle recovery

- automatic crash notification and may-day services
- fleet management
- logistics/supply chain management
- hazardous goods management
- electronic toll collection.

3 Economic impacts

Economic impacts in the transport sector can be driven by several factors. Increases in productivity deliver direct benefits to operations from lower costs, lower congestion and more efficient movement of goods which leads to productivity improvement across the sector.

3.1 Productivity impact on industry costs

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

Estimates of accumulated productivity impacts and cost savings for the transport sector for 2012 and impacts likely to accrue by 2020 are summarised in Table 1 and Table 2 respectively. The represent productivity improvements attributable to the use of augmented GNSS that have accumulated since it was first used in the sector.

Table 1 shows estimates of the contribution of augmented GNSS to savings in operating costs of around $189 million to $232 million in 2012 in the transport and handling sectors compared to the situation where augmented GNSS had not been available. The low estimate reflects a high confidence on the level of adoption. The higher figure reflects an estimate based on our observations of industry practice but which could not be confirmed with certainty.

Table 2 shows our estimates of the contribution of augmented GNSS to savings in operating costs of around $545 million and $772 million in the transport and handling sectors as a result of further adoption of the technologies discussed in this report. The significant difference between the estimates for 2012 and 2020 is the inclusion of additional benefits from the adoption of intelligent transport systems. To achieve these benefits, it would be necessary for augmented GNSS services to be expanded.

Table 1 **Productivity estimates and cost savings for the road transport sector 2012**

	Sector	Assumptions	Impact on costs	Percentage of sector output	Impact on costs	Percentage of sector output
			Low case	Low case	High case	High case
Container Management	Transport support services and storage	Full automation across selected large volume ports Based on adoption levels between 30% and 35%	$ 70,580,250	0.16%	$ 82,343,625	0.18%
Heavy Vehicle Charging	Road transport	Leads to improved roads maintenance and road network management Around 18% savings in costs. The low and high estimates are based on adoption between 1% and 1.5%	$ 33,873,204	0.07%	$ 50,809,807	0.11%
Fleet Management	Road transport	35% Fuel and Transport efficiency Benefits realised in pavement management Decrease onsite staff by up to 40% The low and high estimates are based on adoption estimates between 70% and 10%	$ 84,752,750	0.19%	$ 98,878,208	0.22%

Note: Productivity is expressed as savings in labour and materials to overall sector output

Data source: SKM and ACIL Allen analysis, based on case studies and research

Table 2 **Productivity estimates and cost savings for the road transport sector 2020**

	Sector	Assumptions	Impact on costs	Percentage of sector output	Impact on costs	Percentage of sector output
			Low case	Low case	High case	High case
Container Management	Transport support services and storage	Full automation across large volume ports Based on adoption levels between 40% and 45%	$ 94,107,000	0.21%	$ 141,254,583	0.31%
Heavy Vehicle Charging	Road transport	Adoption of Distance / Location charging – 20% savings in costs. Based on adoption of 2% and 3%	$ 67,746,409	0.15%	$ 84,683,011	0.19%
Fleet management	Road transport	Impact of logistics management 30% fuel savings, 50% reduction in labour costs. 40% adoption for low case 50 % adoption for high case	$113,003,667	0.25%	$141,254,583	0.31%
Intelligent Transport Systems	Road transport	Expanding positional infrastructure supports adoption Low case assumes 10 % adoption High case assumes 15% adoption	$270,487,500	0.59%	$405,731,250	0.89%

Note: Productivity is expressed as savings in labour and materials to overall sector output

Data source: SKM and ACIL Allen analysis, based on case studies and research

The economic impact of these productivity improvements falls under two sectors within the national accounts. The direct impact of productivity improvements from fleet management, heavy vehicle charging and intelligent transport systems falls within the Road Transport sector. The direct impact of productivity improvements in container management falls within the Transport and Handling sector.

The productivity impacts in Table 1 and Table 2 have been combined and are reported in Table 3 and Table 4 below. These productivities refer to cost savings.

Table 3 **Productivity impact on the road transport sector**

	Low case	High case
2012	0.260%	0.327%
2020	0.987%	1.419%

Note: Productivity impact is on costs
Data source: ACIL Allen and SKM

Table 4 **Productivity impact on transport and handling**

2012	0.156%	0.182%
2020	0.207%	0.309%

Note: Productivity impact is on costs
Data source: ACIL Allan and SKM

3.1.1 Impact on sector output

The productivity impacts summarised in Table 3 and Table 4 were used as inputs to ACIL Allen's Computable General Equilibrium (CGE) model, Tasman Global[4], to estimate the impact that theses productivity improvements from the use of augmented GNSS had on the Australian economy in 2012 and the potential benefits that could arise by 2020[5].

The results from this modelling for output from the utilities sector are shown in Table 5.

Table 5 **Increases in sector output**

	Low case	High case	Low case	High case	Low case	High case	Low case	High case
	2012	2012	2020	2020	2012	2012	2020	2020
	$ million	$ million	$ million	$ million	%	%	%	%
Road transport	96	137	442	752	0.2	0.3	0.7	1.1
Transport storage and handling	58	76	92	164	0.1	0.1	0.1	0.2
Total	154	213	534	916	0.1%	0.2%	0.3%	0.6%

Data source: *ACiL Allan*

The table shows that combined output from the two sectors was between $154 million and $213 million higher in 2012 as a result of the use or application of augmented GNSS. This represents 0.1 per cent and 0.2 per cent of total output for the sector.

[4] See overview report for a full description of the CGE modelling approach,

[5] Note that the productivity shocks for other sectors discussed in this report were also entered into the model at the same time.

The combined output of the two sectors is projected to be between $534 million and $916 million higher by 2020. This represents 0.3 per cent and 0.6 per cent of total output for the sector. The projections suggest that significant economic benefits for the transport sector are possible with further adoption of intelligent transport and related logistics systems, drawing on augmented GNSS.

To realise these projected benefits there will need to be wider availability of augmentation infrastructure. This might be from the expansion of a CORS network or through provision of space based or other augmentation systems. This might arise from investment either by the private or by the public sector. Maintaining as much compatibility as possible between systems will be important if the potential of augmented GNSS is to be fully realised.

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Appendix A Case Studies

A.1 Logistics and Fleet Management

The source for this case study is QUBE logistics. QUBE Logistics operates services covering road and rail transport, warehousing and distribution, container parks and related services, and intermodal logistics hubs including rail terminals and international freight forwarding.

Positioning technology has been implemented amongst a number of applications to facilitate, manage and forecast the movement of freight, baulk materials handling and haulage.

Box 1 **Measuring and monitoring truck movements**

> "We have the technology to automatically track and measure truck movements. Drivers in charge of highly sophisticated vehicles should not have to put up with outdated paper-based record keeping. Not when we have the IT and satellite technology to record and report real-time movements,"

Source: Lindsay Fox speaking at the Asia Pacific Economic Cooperation's (APEC) Supply Chain Connectivity Symposium in Singapore in May 2009 that 'black box' technology for trucking management was crucial in promoting efficiency and safety.

There are numerous examples of standalone GNSS integration amongst logistic management systems, such as those used by companies such as TOLL, Linfox and QUBE logistics. Typically, such positioning information operates outside the parameters of precise positioning requirements with accuracies only applicable on the metre level and positional updates not critically reliant on timing.

In saying that, installation of more intelligent vehicle management systems (discussed below) to provide greater relationships to the existing road environment are becoming increasingly prevalent amongst intelligent management decisions such as route optimisation, fuel efficiency, machine maintenance and driver management.

The ability to provide and integrate higher level positioning information (at the where-in-lane level) in the future is becoming a part of these logistics management systems and will facilitate more effective operation.

A.1.1 Benefits

The benefits gained by the adoption of positioning technology in general to improve freight logistics and fleet management include:

- reduction in fuel consumption, estimated at 10%
- 3 % increase in driver productivity from improved logistics management
- minimises idle time to ensure continuity of operations
- improved fleet efficiency (identifying areas of underperformance)
- more efficient time management and route optimisation

- driver risk assessment leading into improved health and safety.

A.1.2 Adoption Costs

Initial adoption costs are relatively minor and consist of largely initial hardware costs that are often packaged as part of overarching fleet management services. Typical stand-alone units commonly implemented amongst these applications are less than $5,000.

A.1.3 Productivity Estimates

Logistics is only effective when there is an adequate supply of information about what is happening at each point in the supply chain, and when available alternatives are well known and understood. By accessing spatial and locational data in real time as part of a more integrated intelligent transport system real productivity gains are possible through improved and more sophisticated logistics management.

Real-Time positioning (whilst not necessarily precise in nature amongst current applications) is now being incorporated within logistics management with custom built evaluation tools and route modelling software that account for vehicle fixed and variable costs, fuel costs and labour costs. Such applications allow for complete financial visibility and viability in real-time to be provided for instant feedback regarding fleet management decisions and dynamic scenario planning.

The productivity estimates outlined above do not require precise positioning. However, provision of greater precision and integrity will facilitate further applications in managing fleets of trucks and in tracking movement of goods being transported.

A.2 Direct Heavy Vehicle Charging

This case study is drawn from the Road Reform Plan drawn up by the Council of Australian Governments in 2011.

Road Transport Infrastructure is one of the only remaining public sector assets yet to undergo major economic reform, whilst there have been a number of steps taken to implement change comprehensive structural reform has not taken hold in the sector.

There are a number of current and emerging challenges that are driving the case for reform, including the delivery of better road freight infrastructure and improving the direct pricing of that infrastructure. One key area which is being currently assessed is heavy vehicle charging. Current road charging methods, funding flows and incentive arrangements for heavy vehicle users and road providers do not necessarily encourage the efficient use, investment, operation, maintenance and management of road transport infrastructure. This in turn imposes avoidable costs on industry, governments and the community.

The existing heavy vehicle charging scheme recovers costs associated with heavy vehicle traffic on the network. It does this using two methods: through a 'Road User Charge' (RUC) collected through the fuel excise; and though separate heavy vehicle registration charges.

Moving to more direct heavy vehicle charging involves replacing the existing schemes with a variable usage charge based on the axle loading of each heavy vehicle and the distance and route (road type) of individual trips. This would provide charges that more closely reflect the costs incurred from heavy vehicle traffic. This would deliver benefits by encouraging:

- the use of more efficient routes by heavy vehicles where there is a choice available, as the charge for using a road is more directly attributed to the cost of a particular heavy vehicle trip
- a more efficient heavy vehicle fleet mix, as operators over time make vehicle choices based on minimising the total heavy vehicle charging costs of road use.

At present there a number of mechanisms being considered for collecting relevant data to support direct heavy vehicle charging. The favoured method is the use of in-vehicle (IVU) telematics linked to GNSS technology[6].

Whilst the accuracies associated for this application aren't required at the sub-metre level, there is significant emphasis on the reliability of service (and hence positioning service) to relay and record correct information to the system operators. The importance of accuracy in this area will depend, to some extent, on the nature of the location based charging and dynamic method adopted for data collection of variable parameters.

Table 6 below, which is sourced from COAG's road reform plan, analysis the various mechanisms by which data can be collected against the relevant parameters for adoption, methods include odometers, tachographs, IVU's and dynamic On Board Mass, all of which except on board mass are capable of measuring distance. In vehicle telematics units are also capable of measuring location.

[6] Business Systems to Support Heavy Vehicle Charging – COAG Road Reform Plan October 2011

Table 6 **Assessment of variable data collection options against key factors**

	Odometers	Tachographs	Hubodometers	IVU – GNSS linked	Dynamic On Board Mass
Data quality and accuracy	Low	High	Low-Medium	High	High
Susceptibility to tampering	High	Low-High	Low-Medium	Low	Medium
Market Capacity	High	Low-Medium	Low-Medium	High	Medium-High
Prevalence in Heavy Vehicle Fleet	Nil	Low	Low	Medium-mostly in large fleets	Low
Set Up Costs	Nil	High	Low-Medium	Medium	High
On Going per Annum	nil	Medium	Low	Low-Medium	Medium
Enforcement Costs	High	Medium	Medium	Low	Low-Medium

Data source: SKM

The findings of the assessment identified in vehicle telematics (IVU linked with GNSS) as the most suitable method for the collection of distance and location based information to support more direct heavy vehicle charging.

A.2.1 Current Implementation

Whilst IVU linked with GNSS technology is considered the most suitable approach to facilitate heavy vehicle charging, its use is currently limited across the sector as implementation is only voluntary at this stage.

One such implementation is the Intelligent Access Program (IAP), which uses the GNSS to monitor heavy vehicles' road use, giving transport operators flexible access to the Australian road network to suit their specific business and operational needs. In return, IAP provides road agencies with confidence that heavy vehicles are complying with the agreed road access conditions.

Long distance road user charging

Two new types of road user charging, both requiring positioning technology, are possible by 2020: mass-distance (and possibly location) based charging for heavy vehicles, and urban congestion charging.

Under IAP (A voluntary initiative), GNSS technology is used to record the movement of trucks on a limited number of defined routes. Trucks are limited to certain weights in order to protect roads from damage costs – roads deteriorate with use, and the amount of deterioration is strongly related to axle weight (known as the fourth power rule). IAP trucks are allowed to carry heavier loads than would normally be permitted, in exchange for paying additional charges to compensate for the additional damage to the roads.

Congestion charging

Further to IAP and Heavy Vehicle Reform Charging mechanisms, urban congestion charging is another potential use of positioning technology. Vehicles would be charged according to location and time of day, with high prices in peak periods in congested areas, and lower prices otherwise. Such price signals have proved effective in reducing congestion in Singapore and Stockholm, using standalone GNSS technologies within IVU.

There is also an effective congestion pricing scheme in London using a more primitive and costly numberplate recognition technology. The schemes are best introduced as part of the package where public transport capacity is improved in order to accommodate extra passengers diverted from road, and the extra revenue is spent on economically worthwhile transport projects

Congestion charging is frequently proposed in Australia, for example by Infrastructure Australia and ACIL Allen. However there is opposition from some state governments and road users. There is a substantial challenge to explain the benefits, and substantial preparation would be needed to set up and trial the system and to put in place the associated public transport improvements. For the purposes of the study is assumed that congestion charging is not likely by 2020 in the low case and some estimate of congestion charging in the high case.

A.2.2 Benefits

The expected benefits from changing heavy vehicle behaviour include lower total heavy vehicle operating costs for a given freight task and improvements in road safety from having fewer, more productive vehicles on the road.

In addition the ability to link technology with programs such as AIP which will collect and allow analysis of road freight movements could be used for both improved fleet management and for the road transport industry to optimise heavy vehicle operations in terms of safety, efficiency and productivity[7], potential benefits include:

- avoided cost of road wear from more efficient use of the existing road network
- changes in vehicle operating costs from switching to larger, more productive vehicles, partially offset by potential increases in kilometres travelled
- potential fleet management operator benefits, from the use of information provided by in-vehicle units
- safety benefits from reduced vehicle kilometres and from the use of in-vehicle technology, resulting in lower crash costs and reduced injuries and
- improves environmental outcomes from more intelligent management of road networks.

[7] COAG Road Reform Plan, (CRRP), 2011, Business Systems to Support Heavy Vehicle Charging, http://www.roadreform.gov.au

A.2.3 Adoption Costs

At this stage, the adoption costs related to road charging reforms are fairly minimal with explicit hardware costs for standalone GNSS IVU within the order of hundreds of dollars. The majority of current and proposed expenses will be within the wider adoption of the system used to collate, evaluate and administer the charging mechanisms.

As the requirement for more precise positioning grows so too will the costs associated with developing appropriate augmentation infrastructure.

A.2.4 Productivity Estimates

Productivity estimates are probably best estimate in terms of future benefits at this stage, with minimal current realisations of benefits.

Overall, initiatives such as the COAG heavy vehicle reform suggest positive net benefits in the order of 5 to 7 billion over 30 years. The contribution of positioning systems to this net benefit would be speculative.

Overall and assuming a take-up of 8,400 vehicles, IAP is estimated to generate a net present value (that is, present value of benefits less costs) of $264.2 million over seven years (allowing for two implementation years) and a benefit cost ratio of 5.4. Across all applications, the authorities' net present value is estimated to be $80.9 million and the operators' net present value $183.3 million. These results do not appear highly sensitive to assumptions about benefits and costs (ACIL Tasman 2008).

Net benefits will be realised through more direct road use charges with the introduction of distance-location charging methods (supported via GNSS) anticipated capturing a projected $6 Billion across fleet wide introduction (CRRP 2011).

A.3 (Cooperative) Intelligent Transport Systems – CITS

This case study is drawn from AUSTROADS. Austroads is the association of Australian and New Zealand road transport and traffic authorities. Austroads promote improved Australian and New Zealand transport outcomes by providing expert technical input to national policy development on road and road transport issues

C-ITS facilitates the connection of road users to their road environment via the connection and exchange of real-time information about the road environment, such as

- vehicles, infrastructure, non-infrastructure features and other objects
- road and traffic conditions
- events
- threats and potential hazards.

This allows the end user to be better informed and safer decisions in regard to transportation networks. In order to achieve this, the system needs to exchange data with respect to each vehicle's location, direction and speed amongst other data requirements. (AARB Project Team 2012).

C-ITS is the natural extension of a combination of technologies and system developments including fleet management and logistical systems, toll systems, freight management and of course a range of positioning techniques such as triangulation methods, re-identification and standalone GNSS systems. Where C-ITS differentiates itself from other transport related management systems is in the requirement for advanced precise positioning.

The exact positioning requirements that have been broken down are as follows:

1. Road-Level Applications – Metre level Positioning at approx. 1 sec (1 Hz)
2. Lane-Level Applications – Sub Metre level positioning at approx. 1 Hz
3. Where-in-Lane Level Applications – Decimetre level positioning at 0.1 sec (10 Hz).

Currently, such ITS systems are being realized in Europe, Japan and USA where they have access to SBAS that can fulfil the positioning requirements of the system. However, Australia does not currently possess such positioning augmentation levels and as such is currently not in a position to reliably support the implementation of ITS.

There is the inherent risk that without infrastructure development (be it at ground or space borne augmentation) that Australia will miss out on both the many environmental, safety and economic benefits that such systems support.

Benefits

The benefits of such systems are:

- improved Safety features
  - collision warning
  - emergency braking
  - speed limitation and safety distance
  - road condition assessments
  - intersection and road feature information
- route optimisations
- vehicle management and road maintenance
- fuel optimisation
- increased system(s) interoperability.

Intelligent transport systems integrate currently available and emerging information, computer, communications and vehicle-sensing technologies into transport infrastructure and vehicles in order to monitor and improve the safety, efficiency, management and operations of vehicles and transport systems. There is considerable evidence collected from within Australia and abroad that ITS can produce considerable reductions in accident rates and improvements in transport efficiencies (ACIL Tasman 2008).

Improvements to the efficiency of transport can also yield environmental benefits. For example, it is estimated that ITS will produce fuel savings of between 2% and 13% and reduce emissions by between 5% and 15% (Standing Committee on Transport and Regional Services, 2002).

Putting this in context, in 1998 Australia's transport sector contributed about 12% to the total of Australia's greenhouse gas emissions, with road transport accounting for 81% of these emissions. It is therefore estimated that a reduction of road transport related emissions could reduce Australia's total greenhouse gas emissions by between 0.5% and 1.5%.

A.3.1 Adoption

Whilst ITS has been implemented across mainly USA and Japan (in its initial stages), Australia is not in the current position to be able to support the roll-out whilst positioning remains ambiguous. However, there is movement to place Australia in a position to be a fast adopter of the technology.

The key features to the positioning component that need to be specifically addressed include:

1. accuracy
2. integrity
3. continuity
4. availability
5. interoperability
6. timeliness.

Project adoption costs for C-ITS include indicative capital expenditure between low level hardware (Single frequency GNSS) to high level hardware (GNSS combined with Locata and IMU) ranging to several thousand dollars per unit.

Requirements for certain GNSS and positioning sensors are dependent on a number of predictions such as the availability of future positioning augmentation. One of the biggest cost dependencies will be influenced by market uptake (AARB 2012).

A.4 Container Terminal Management

This case study is based on consultation with Patrick Pty Ltd who operate four container terminals throughout Australia (Melbourne, Brisbane, Sydney and Fremantle. The company has the capacity to manage up to 3.9 million TEU (Twenty Equivalent Units) of assets per year. Typically, there are two facets to container management: waterside operations (vessel unloading); and transport operations (truck unloading). The effective storage of containers within the dock space is of critical importance to best practice.

The movement of containers is facilitated by large mobile straddles which are able to attach/detach containers (various straddles accommodate different container sizes) and transport them to a desired location. Of importance to effective operations is the locality of such containers as they are loaded/unloaded.

As such, precise GNSS is used to capture locality data, referenced to a regularly updated site locality plan, at the detachment/loading points from the straddle. This information is then linked to an overall management system, which when imposed with certain site constraints, will effectively position every container its content, mass and other useful information as it is moved through the transportation process.

Figure 1 **Container terminal operations**

Data source: Patrick 2012

Such information on locality is important to a number of areas of business operation including improving transport and fuel efficiency, effective container organisation, and even detail such as management of asphalt/pavement stress and conditions.

East Swanson dock in Port Melbourne is a semi-automated site reliant on an augmented GNSS system comprising two localised base stations broadcasting correction (at DGPS level) to the 36 operational straddles around the facility. The required accuracies to efficiently operate within this system and reliable position containers are plus or minus 30 centimetres. It is worth also noting that no height component of the DGPS information is used within location services and constraints relating to time of container dispatch are used to determine the stacking order of multiple containers.

Within fully automated sites, such as Fisherman's Island in Brisbane, the accuracy requirements have been increased to plus or minus 2 centimetres due to the requirements of the automation process.

In addition to effective container management, the additional bonus of full site automation is that pavement/asphalt stress is reduced due to the dynamic location of loading bays which are regularly shifted in the order of metres to reduce continual loading stress. Costs have been estimated at approximately $1 million per year in loading bay maintenance, with larger costs for redevelopment works on cycles of about 5-10 years. Reduction in loading stress reduces these ongoing maintenance and overhaul costs by approximately 35%.

A.4.1 Benefits

The overall potential benefits of full Automation throughout Patrick sites have been estimated at 55 million per site, based on current day figures.

- fuel and transport efficiency
- reduced machine wear and tear
- pavement / asphalt management
- improved safety (reduced collisions and transport related risks)
- reduced driver injuries due to remote straddle operation
- route optimisation
- reduction of labour through automation
- storage management
- fleet monitoring.

A.4.2 Adoption Costs

The investment into automation of port facilities was largely underlined by the advent of the worker strikes of 1998, with Patrick identifying the need for a reliable and efficient system to be developed to improve potential lost operation risks, increase efficiency and minimise safety risks.

Initial investment outlay in the late 1990's was in the order of $250 million given the more excessive equipment costs during that period. However recent figures quoted have seen development and system upgrade costs reduce to approximately 1.5 million per site.

Patrick has recently announced the full automation of its Port Botany site in Sydney comprising 44 fully automated Straddles. The investment in this system totalled $348 million.

A.4.3 Productivity Estimates

Productivity estimates are currently being realised from operations particularly associated with automated and semi-automated straddles.

It is estimated that fully automated facilities, such as those in place at Fisherman Island, have reduced current staff levels by up to 50%. Sites operating under semi-automation have reduced levels of staff by up to 33% and have recorded mass savings in a number of key areas.

Previous to the adoption of GNSS as part of the container management process, hand-audits were conducted as part of the management process which required full site shutdowns and limited verification process. Inefficiencies associated with such practice added an additional 20-30% cost with overall processes.

Fuel Costs have been estimated at 1000 litres per Straddle per day (continuous operation), a perceived 30% reduction in fuel from smoother operation and controlled speeds puts an estimate of savings around 109,500 litres of fuel per Straddle per year, or an approximate saving of close to $200k per year at Current Diesel Costs.

> "The redevelopment will increase our throughput by almost 50,000 containers per year and, with additional investment in future years, will give us the ability to increase to more than 2.8 million containers per year in line with increasing demand. " (Patrick 2011)

A.4.4 Safety

There are obvious safety benefits to adopting automation as part of operations. These include reductions in driver fatigue and strain, collisions and loading incidents.

> "In the first year of automation at our Brisbane AutoStrad™ Terminal, we achieved a 75% reduction in safety incidents, increasing to a reduction of 90% in following years. It is only logical that we look to replicate this success at our biggest container terminal at Port Botany." (Patrick 2011)

Appendix B Level of Adoption

The demand for transport and the availability of vehicles is often changing quickly; real time access and analysis of these variables can yield significant cost savings. As such, there is a fundamental underlying interest in maximising productivity benefit through adopting intelligent transport systems.

The transport industry was one of the first to employ GPS as means of tracking vehicles and freight movement and is already widely adopted. Tracking goods in transit now utilises GNSS which increasingly utilises integrated systems of GNSS and electronic mapping systems for total integrated systems (such as in car navigators) (ACIL Tasman 2008). As previously mentioned, this is widely adopted, however does not relate directly to precise positioning applications due to the relatively low accuracy requirements of the system at approximately the 10m level.

In regards to container management, full automation adoption is likely across the majority of Australia's port facilities due to the efficiencies that large projects (as demonstrated by Patrick) are currently demonstrating. The current industry adoption of semi-automated facilities sits at an estimated 80% with full automation representing the remainder. Full automation adoption rates are likely to change significantly over the coming decade as advances in GNSS positioning, reliability, coverage and compliance coupled with demonstrated realised long term benefits, convince the industry to become reliant on automation.

B.1 Adoption Factors

Adoption is driven by a number of factors. More broadly speaking, the classic textbook reference by Rogers (1964) identified a five-step decision process involved in technology adoption and diffusion:

- Knowledge – potential adopter becomes aware of an innovation but has no particular opinion of it (this could be via advertising or through word-of-mouth)
- Persuasion – the potential adopter seeks further information to help form an attitude toward the innovation
- Decision – the potential adopter engages in activities that lead to a choice to adopt or reject the innovation (the process is internal to the person and can be difficult to measure empirically; however considerations of price and perceived usefulness/necessity will play into this decision)
- Implementation – the innovation is adopted and put into use (e.g., user installs geospatial data software or uses car navigation aids)
- Confirmation – person evaluates the results of an innovation-decision already made which may affect decisions such as whether to continue using the innovation or return to previous status quo (e.g. remove software or return car navigation aid).

Rogers also estimated the categories of adopters as being innovators (2.5 per cent), early adopters (13.5 per cent), early majority (34 per cent), late majority (34 per cent) and laggards (16 per cent). These reference figures were adopted for the current report, as they were based on and have been broadly corroborated by many case studies including those in the original contribution by Rogers.

B.1.1 Fleet Integration

Given that C-ITS tries to relate the driver to the immediate environment, including other vehicles in the network, the effectiveness across various applications is not completely realised until all (or at least the vast majority) of vehicles have the system installed. This is a significant challenge due to the costs of updating vehicles across many different demographics and could be a 40 year exercise if not specifically enforced by regulatory agencies such as the TCA.

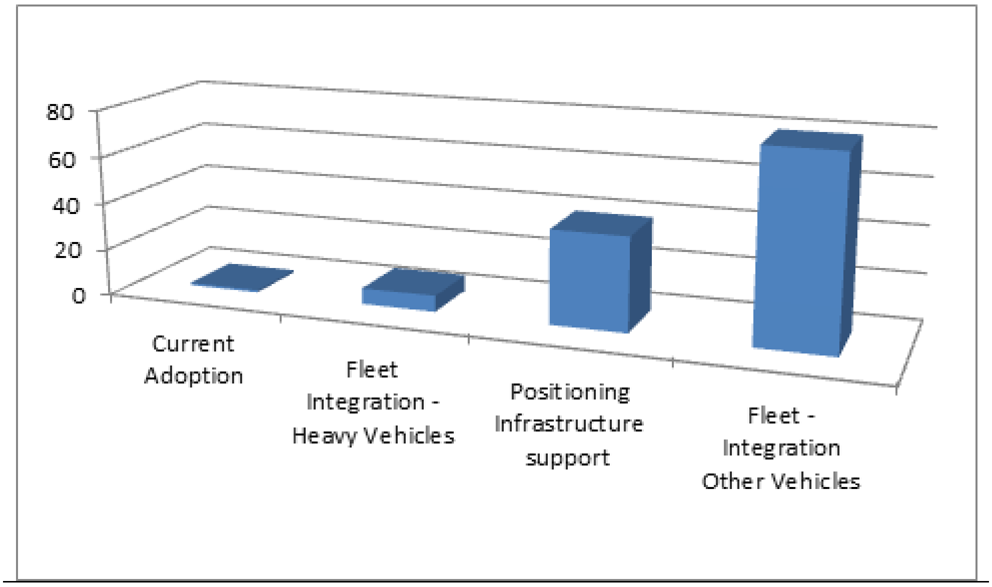
A more likely and immediate scenario is to see adoption of C-ITS across smaller sample road users, most likely Heavy Vehicles. This is much more probable and realistic given the relative reduced numbers and greater operator net benefits (after allowing for adoption costs).

B.1.2 Positioning Infrastructure to support where in lane positioning

To realise the full benefit from C-ITS, in particular the safety benefits, sub metre, where in lane positioning is a requirement. This is a significant challenge to support given the breadth of Australia's road networks and would require substantial upfront investment.

An indication of the impact on adoption levels of development of systems and infrastructure is provided in Figure 2. The graph demonstrates the estimated rise in adoption level as the various adoption factors are overcome through developments.

Figure 2 **Stages in adoption of C-ITS**



Data source: SKM

Figure 3 shows the levels of Adoption of C-ITS as adoption impediments are overcome. There is likely to be a significant increase in adoption of C-ITS when accurate positioning infrastructure becomes more widely available. This is likely to involve not only the extension of more traditional augmented GNSS systems but also extension of GNSS consistent systems into tunnels and metropolitan areas aided by technologies such as Locata. The ability of GNSS receivers to report position seamlessly between different positioning infrastructures can be expected to increase the demand for such systems by transport operators.

As these are partially or fully overcome there will be a direct correspondence with transport adoption of positioning systems and technologies. Table 7 below is speculative but an attempt to project the likely technological advances in positioning adoption factors.

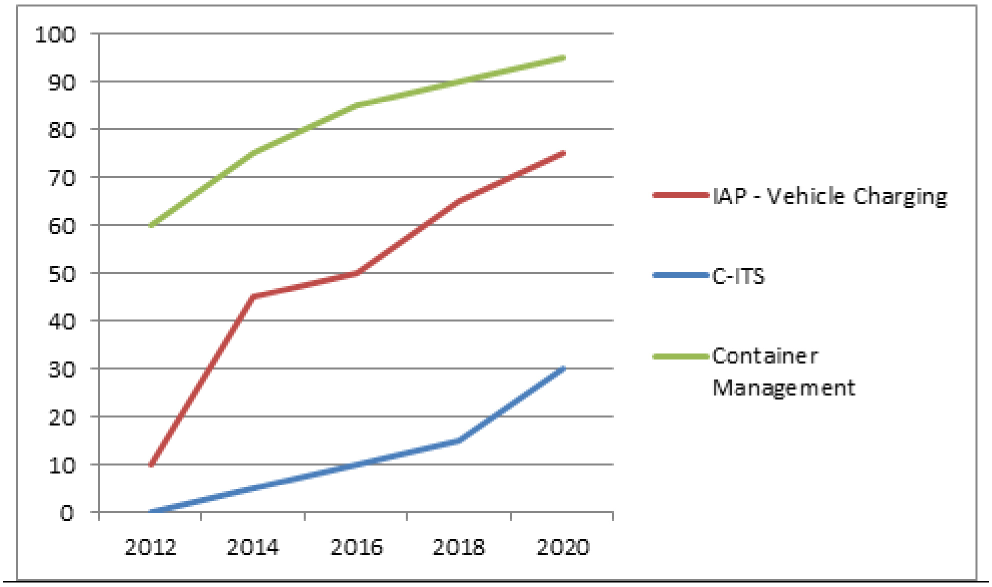
Table 7 **Estimated timeframe for overcoming adoption factors – Transport**

	Optimistic	Medium	Conservative
Fleet Integration - Heavy Vehicles	2014	2018	2020
Positioning Infrastructure Support	2016	2020	2025
Fleet Integration - Other Vehicles	2020	2030	2040

Data source: Data source: SKM

Figure 3 below displays the likely increase in adoption of GNSS precise positioning technologies amongst the Transport sector. Three curves have been estimated based on the implementation of GNSS positioning amongst transport applications identified throughout the case studies.

Figure 3 **Adoption rates**



Data source: SKM

Appendix C Social and Environmental

Given the anticipated growth in transport networks and activities Australia wide over the coming decade there is an increased emphasis on the sustainable management and use of existing and new infrastructure. As such, the growing reliance of intelligent platforms like C-ITS will play a critical role in providing information to best utilise the many existing and projected new users of transport networks.

Reducing congestion, fuel consumption and the carbon footprint associated with road users will all be greatly aided by the implementation of positioning amongst interactive transport management systems. This will be achieved through the correct and reliable relay of the spatial relationship between vehicle position and greater road environment.

Box 2 Reducing environmental impact

A commitment from Woolworths' transport to reducing its environmental impact of its fleet, including a goal to reduce carbon dioxide emissions by 25 per cent per carton by 2012 has led to an investment in transport management systems to reduce truck trips and drive supply chain efficiency.

The rollout involved specifically designed trailers and technology to plan, optimise and track outbound freight movements. The technology optimises transport movements from distribution centres (DCs) to stores and utilises truck back loading capacity.

Reported benefits include "real time" visibility of the vehicle fleet which enables proactive management of deliveries into stores.

Source: Woolworths 2010

Not only will environmental concerns be addressed through the integration of intelligent spatial information through a common platform, but improvements in safety for all road users will mark a significant step forward for a community of road users who have been exposed to a prolonged environment of hazardous road conditions and severe injury and fatality associated with road accidents.

Precise positioning is already realising many in-vehicle safety features (as previously discussed) in other countries. As it begins its adoption in Australia, not only will it support the immediate vehicle safety of drivers, it will also gather intelligence to support better and safer use of the larger surrounding road networks and all commuters who are dependent upon them.

Appendix D References

AARB Project Team (2012), *Austroads Report – Vehicle Positioning for C-ITS in Australia,* Austroads Project No: NT1632, September 2012, ARRB Group.

ABS. (2012). *Productivity tables 5260.0.55.002.* Canberra: Australian Bureau of Statistics.

ACIL Tasman 2009, *The economic value of spatial information in Australia,* Report to the CRC SI

Allen Consulting Group 2007, *The Economic Benefits of Making GPSnet Available to Victorian Agriculture*, Report to the Department of Sustainability and Environment, July.

Allen Consulting Group 2008, *Economic Benefits of high resolution positioning services*, Report to the Department of Sustainability and Environment, November.

COAG Road Reform Plan (CRRP), 2011, *CRRP Feasibility Study – Final Report to COAG,* http://www.roadreform.gov.au

COAG Road Reform Plan, (CRRP), 2011, *Business Systems to Support Heavy Vehicle Charging,* http://www.roadreform.gov.au

COAG. (2011). Business Systems to Support Heavy Vehicle Charging. Council of Australian Governments.

Lateral Economics. (January 2009). *Nation Building for the Information Age.* Canberra: Lateral Economics.

SKM Various Authors (2011) CRRP – Compliance Cost Model v 2.2

UN Office for Outer Space Affairs. (2010). *Current and Planned Global and Regional Navigational Satellite Syetems and Satellite-based Augmentation Systems.* New York: United Nations.

D.1.1 Websites:

Patrick, 2012, *Official Home Page,* http://www.patrick.com.au/w1/i2/, accessed 29th September 2012.

TeloGIS Fleet Management, http://www.telogis.com.au/solutions/fleet/, accessed 3rd October 2012.

Austroads, 2012, *Official Home Page,* http://www.austroads.com.au, accessed 1st October 2012.

Transport Certification Australia (2012), http://www.tca.gov.au/regulatory-telematics/iap, Accessed 10th October 2012

ACIL ALLEN CONSULTING

Precise positioning services in the rail sector

An estimate of the economic and social benefits of augmented positioning services in the rail sector

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

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Executive summary

Augmented GNSS in the rail sector currently has applications in surveying track, locating infrastructure, managing train movements (mainly in long distance applications) and in management of rail operations at ports.

It is increasingly being used in track surveying and location of infrastructure which requires precision of around 2 cm accuracy. This applies to all sectors – long distance, mining and metropolitan systems.

There is potential for precise GNSS to be used in Automated Train Management Systems (ATMS) that require accurate and reliable positioning systems to identify the leading and trailing edge of trains and relay its position to a central train control systems.

Current systems use track circuits to determine whether a train is on a section of track (between two signals), but do not locate where the train is on that section. More precise location information is relayed verbally by the driver to train control.

Automated Train Management Systems (ATMS) can replace track side signalling with in cab displays to provide precise location of trains, to support digital network control centres and other train control mechanisms for use by both drivers and controllers. The advantage of ATMS is that it can increase rail capacity through closer train operations, improved reliability, efficiency and flexibility and increased safety through better management of speed limits.

Accurate and reliable positioning from augmented GNSS could also facilitate the opening up of further value-adding services, such as driverless trains, advanced forms of train protection and control, improved maintenance and track monitoring.

ATMS is likely to find application in long distance systems but metropolitan systems are more likely to adopt European Train Control Systems (ETCS) that depend on track transponders rather than GNSS systems.

ACIL Tasman has estimated the likely productivity benefits and savings from the use of precise GNSS for track surveying and management and the future use of ATMS by the Australian Rail Track Corporation and in 2020 by the dedicated mine rail systems:

- accumulated benefits of between $1.8 million and $3.4 million (0.02 per cent and 0.03 per cent of the value of production in the sector) in 2012 attributable to lower costs and improved productivity in the use of precise GNSS in surveying track and rail infrastructure.
- benefits rise to between $9.5 million and $10.1 million (around 0.08 per cent of the value of production in the sector) by 2020 based on installation of ATMS on ARTC lines by 2020.

The impact on the economy would be reduced operating costs for freight railways (both train operations and signal maintenance), a deferral of the cost of investing in capacity enhancements, more competitive rail freight (hence a shift from road freight) and flow-on benefits to the wider economy through lower freight rates.

The high case would require wider coverage of GNSS augmentation across Australia and compatibility between different augmentation systems available to the rail sector.

Modelling indicated that the use of augmented GNSS had not had a significant impact on output from the sector in 2012. However output could be up to $12 million higher by 2020 on the above assumptions.

These results could be higher if metropolitan systems adopted ATMS systems. However to utilise augmented GNSS, there would need to be further development of localised GNSS compatible positioning systems for use in tunnels. There is no technology currently available to do this task.

Key findings

- The most common use of augmented GNSS in the rail sector to date has been in track and signal placement and for automated train management systems for long distance rail.
- There is potential for precise GNSS to support Automatic Train Management Systems. The Australian Rail Track Corporation (ARTC) is investigating the use of such systems for its longer distance track infrastructure and systems. The metropolitan rail systems have however adopted the European Train Control Systems (ETCS) which relies on in track transponders and do not use precise GNSS for positioning.
- High resolution GNSS is needed for automated stevedoring at ports and, after significant hurdles are overcome, might be deployed in rail terminals with a similar gain to efficiency.
- Positioning technology is being developed for automatic train management, which will allow wayside signals to largely be replaced by in-cab signalling. Most of this (outside metropolitan areas) will require augmented GNSS for integrity monitoring and reliability criteria.
- Allowing trains to be safely operated closer together would have system wide capacity benefits. Such developments are still some way off in the Australian rail sector.

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 rail 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 rail sector

The rail industry has at least three distinct sectors: bulk freight (ores, minerals and grains), non-bulk and break-bulk freight (containerised goods, non-containerised manufactured goods), and passenger transport (mainly urban and regional).

The rail sector is characterised by long lived investments. Many locomotives are 20-30 years old; wagons are typically used for 30-40 years. Signalling systems are maintained for 20-50 years. Investments in new track can be expected to last for at least 50 years if adequately maintained. This has implications for its take up of new technologies.

Within Australia, rail dominates mineral freight and non-bulk (container type) freight between the east and west coast. It struggles elsewhere with a low market share for non-bulk freight on the east coast, low returns on grain freight, and with large subsidies on urban services.

Productivity improvements would lower costs and allow rail services to better compete with cars and trucks.

2.1.1 Common themes

Non-augmented GNSS is a valuable tool used by both track managers and train operators. GNSS applications in rail have helped to improve asset management, the efficiency of asset use and provide improved customer services by tracking trains. These uses generally do not require high resolution positioning.

Precise GNSS currently has applications in surveying track, locating infrastructure, managing train movements mainly in long distance applications and in management of rail operations at Ports.

Accurate and reliable GNSS could facilitate the opening up of further value-adding services, such as driverless trains, advanced forms of train protection and control, improved maintenance and track monitoring. However the existence of significant legacy investments combined with cost has resulted in alternative approaches to precise GNSS in most urban rail systems.

A lack of precision and reliability in GNSS positioning in the past has led to the development of alternative or parallel technologies to establish train position. Any positioning system needs to be robust to trains passing through tunnels, areas of sparse coverage (such as the Nullarbor desert) and possible interference from overhead electrical cables or proximate steel surfaces.

At present the main use of augmented, high resolution, positioning in the rail industry is surveying of track. Modern train management requires accurate maps of the railway (centre line, curvature and gradient), and location of signalling infrastructure. Positioning of track is typically required to be accurate within a few centimetres. Historical maps of asset locations are not sufficiently accurate for some modern applications and so an exercise of remapping (and recording new track placements) is underway in many states.

Augmented GPS allows for much more accurate maps to be drawn and recorded with less effort than previous methods including traditional surveying.

2.1.2 Bulk freight

Bulk freight comprises ores, minerals and grains over short to medium distances from mines to ports or from grain silos to ports. The goods are characterised by homogeneity of the products in each wagon (different grades of ores, minerals and grains exist but are segregated).

In the case of ores and minerals, this freight sometimes moves on dedicated track owned by the mines, and sometimes moves on shared track managed by State track authorities or Australian Rail Track Corporation (ARTC).

In bulk freight applications the main use of augmented, high resolution, positioning is in surveying of track. Accuracy of around 2 cm is required as in most surveying activities.

There are many other applications of lower resolution GNSS, including:

- locating locomotives and ensuring appropriate asset utilisation as a result
- cost savings from driverless trains in remote areas (e.g. Pilbara).
- optimised driving, which adjusts acceleration to take advantage of topography and requires positioning to identify when to accelerate/brake and what the optimal speed is for minimum fuel consumption.

While there is potential to use augmented GNSS for control and train management in the future, progress is expected to be relatively slow in following up these applications. The case study of the use of GNSS by Rio

Tinto in its Pilbara operations shows that most of the uses of GNSS, such as driver and train monitoring, do not currently require more precise GNSS measurement. However monitoring of train movements in railway yards and in tunnels does require augmentation because of signal bounce and interference. Augmented GNSS has the potential to address such problems and may play a greater role in the future.

2.1.3 Non-bulk and break bulk freight

Non-bulk and break bulk freight on rail typically relates to inter-capital movements of manufactured goods on intermodal services. That is, goods which move by truck to a terminal, are then loaded on to a train, move by train on the 'line haul' between cities, are unloaded at a receiving terminal before being picked up by truck and delivered to the customer.

Intermodal services offer an alternative to road transport between cities. Intercity freight movements mostly occur on track owned and managed by Australian Rail Track Corporation (ARTC), a government owned entity. Movements between Tarcoola and Darwin take place on a railway owned and managed by Genesee and Wyoming Australia. Track between Kalgoorlie and Perth, and in Sydney, is leased to ARTC.

Augmented GNSS is currently used by ARTC for surveying the track. The major impetus for this is the intended roll-out of ARTC's Automated Train Management System (ATMS), which is a form of advanced train protection and control which will also yield capacity benefits and reduced infrastructure costs[1]. High resolution GNSS creates efficiencies in this surveying task by reducing the time and labour required in setting out and measuring coordinates. It also provides the opportunity for more efficient data capture and transmission to central data bases and can where necessary be used with remote sensing technologies to monitor and in some cases control systems..….

Other GNSS uses by ARTC include:

- locating signalling assets
- locating maintenance issues on track, as recorded by specialised maintenance vehicles.

Logistics value-add in conjunction with rail operations

Train operators offer services between cities and sometimes incorporate other value-added services such as freight planning, warehousing and tertiary (to customer) delivery.

The dominant train operator is Asciano. As well as Asciano, train operators include the newly-privatised Queensland Rail National (now called Aurizon), and Specialised Container Transport (SCT). The case study of the use of

[1] ATMS is one of the case studies detailed below.

precise GNSS by Asciono (see Section A.3 in Appendix A) shows that there is a significant demand for millimetre accuracy in port operations such as those at Botany.

Lack of augmented GNSS in the past has resulted in this positioning in container terminals being supplied by GNSS augmented by radar positioning. Had high-precision GNSS been available ten years ago perhaps this would be the sole positioning system in use.

GNSS is used by the train operators for:

- asset location and monitoring
- fuel economy software which calculates the optimum driving profile for the journey, to reduce the need for acceleration and subsequent (wasteful) braking
- monitoring the efficiency of train loading by monitoring the path of fork lift trucks
- monitoring the progress of trains within track segments
- recording of journey progress for customer tracking
- recording the location of incidents that cause delays or where potential maintenance is required
- GNSS triggers of important events, such as shift changes, required on-train activities or procedures.

In most cases however, accuracy is only required to 100 metre accuracy which can be supplied with stand-alone GNSS. However augmented GNSS could be valuable in the future for managing and monitoring train movements in shunting yards and in tunnels where stand-alone GNSS is either unreliable or unavailable.

2.1.4 Passenger rail

Urban passenger railways rely heavily on long established existing signalling systems and safe working systems. The location of trains is identified via track circuits and signalling equipment.

These technologies were all established before GNSS was a commercial reality, and if they were to be replaced it would be likely that augmented GNSS could cost effectively fulfil a number of these functions. The most likely system to be followed in Australia is a European one based on transponders whereas the ARTC system will be augmented GNSS-based. European Train Control Systems (ETCS) were developed before the availability of GNSS and have not embraced augmented GNSS at this point in time.

Similar to rail freight operations, RailCorp (soon to be split into NSW Trains and Sydney Trains) is currently using high resolution positioning to survey its existing track before deploying advanced train protection systems. Other capital city railways are likely to need to undertake this level of precise surveying prior to their investments in advanced train protection and control systems.

3 Productivity impacts

For this study, ACIL Allen used case studies of applications in the rail industry in Australia to provide data on the productivity impacts of specific applications. Levels of adoption of these applications were then used to estimate likely national benefits for 2012 and potentially for 2020.

Four case studies were selected for the rail industry. These were:

1. Automated Train Management System (ARTC)
2. Fuel saving technologies (Asciano/all train operators/bulk haulers)
3. More efficient surveying in anticipation of European Train Control Systems (RailCorp)
4. Improving the efficiency of asset use (Rio Tinto/Asciano).

The first of these promises significant productivity improvements and is discussed in this paper. The others offer lower productivity benefits, and the third is out of scope because it uses older signalling infrastructure and track circuits does not involve augmented GNSS although it does indicate potential benefits if augmented GNSS were to become more cost competitive. The case studies are covered in Appendix A.

3.1 Australian Rail Track Corporation (ARTC)

ARTC is the track manager for the interstate track between Perth (leased from Kalgoorlie-Perth), Adelaide, Melbourne, Sydney (leased on the South Sydney Freight Line), and Brisbane.

ARTC has invested considerable time and money into developing Automated Train Management System (ATMS) which uses augmented GNSS to identify the front and back of a train, and frequently relay its position to a central train control system.

Current systems use track circuits to determine whether a train is on a section of track (between two signals), but do not locate where the train is on that section. More precise location information is relayed verbally by the driver to train control. Typically only one train is allowed on a track section at a time, and the presence of the train turns the signal behind it red.

Once operational, ATMS will:

- replace trackside signalling with in-cab displays of movement authorities to drivers
- provide precise location of trains both front and rear

- provide new digital network control centres, each capable of controlling all traffic on the ARTC national network
- provide a backup capability in the event of failure at one control centre
- provide enforcement of override controls on each locomotive if a train is at risk of exceeding its authority to move forward on a certain track segment
- provide switch settings and automatic route clearances
- provide information (voice and data) to all locomotives via the Telstra 3G National Network.

The advantages of ATMS are that the position of the train is known within a few metres, and other information such as time, velocity and train health can be relayed with this information. Once the concept has been proved and safety accredited the advantages of ATMS will be:

- increased rail capacity through closer train operation
- improved reliability through better on-time performance
- improved efficiency and flexibility of the rail network
- increased safety through authority and speed limit enforcement
- additional protection for trackside workers
- operator savings through less fuel consumption, less wear of wheels and brakes, and fewer train crew hours
- reduced operation and maintenance cost for the trackside infrastructure.

ATMS was trialled on a section of track between Crystal Brook to Port Pirie and Stirling North.

In advance of trains running on these sections (some 100 kilometres of test-route) the track was surveyed to within 2 centimetres positional accuracy. The surveying of track is time consuming and expensive – ARTC manages some 11,000 kilometres of track around Australia and would benefit from cost efficiencies in surveying the track using high resolution GNSS.

3.1.1 ATMS and GNSS

The ATMS equipment uses GNSS which locates the front and end of the train within 2 metres accuracy (interstate freight trains are 1200 to 1800 metres long). Trains must pass through the Nullarbor and also through tunnels and all GNSS must be extremely reliable. Because of the absence of reliable and cost effective high resolution GNSS coverage of the ARTC network the ATMS locational systems use both GNSS and inertial monitoring systems (such as tachometers) to determine position on the track.

If ARTC could rely on augmented GNSS alone (and this would need to be extremely reliable) then perhaps ATMS set-top boxes would need less equipment and therefore less equipment to integrate with train systems, which would save money per box and per train. ARTC was unable to make an estimate of what this cost saving might be.

3.1.2 ATMS implementation costs and benefits

The current cost of on-board equipment is some $100,000 per locomotive; this includes location equipment as well as the computer which interprets the train authorities, velocity, position, and other information.

This would need to be installed on about 700 locomotives for the interstate freight task. ATMS on-board equipment could also be installed on regional train services, metropolitan rail services and maintenance equipment (e.g., high rail vehicles, grinders, etc.), but this is less likely because of the lower capital value of maintenance vehicles.

There would be ATMS installation costs (integrating the locomotive braking systems and inertial information to the ATMS interface) which are significant, but not yet known to ARTC.

If the GNSS signal is lost, trains can run without using ATMS, but the distance between trains is lengthened and instructions are verbally transmitted to drivers. This reduces the capacity of the railway, increases journey times for goods, and is less safe.

ATMS could double ARTC's track capacity

ATMS's ability to increase capacity and defer capital expenditure on track is significant. The network is 10,000-11,000 kilometres long. The cost to double capacity would be between $10-20 billion, estimates of $1m per kilometre are not unreasonable. **ATMS would be able to more than double ARTC's track capacity, it would allow trains to run with 4 minute headways (time between trains) – this is 3-6 times the current operating capacity of the railway.**

Avoiding track duplication has externality benefits too, since duplicating track in urban environments brings track closer to houses, with increased noise and pollution costs.

Augmented GNSS could provide accurate time stamping to control centres

Accurate time stamps for GNSS data are important because messages to the train control centre are time stamped with the GNSS time. This is particularly useful if a train is involved in an incident or reporting an incident. It is also useful for monitoring progress to the schedule. The higher reliability of augmented GNSS would be an advantage here but it is not always considered necessary in the industry for these purposes.

3.1.3 Other GNSS uses at ARTC

Maintenance vehicles journey along the track recording the location of worn or faulty track. Accurate recording would be beneficial, but not essential. Maintenance crews can locate the issue if provided with coordinates accurate within a few metres.

3.1.4 Conclusion

High resolution GPS would reduce costs in surveying track and it could lead to a reduction in the cost of on-board ATMS equipment. GPS based ATMS would have significant productivity benefits:

- improvements in capacity,
- flexibility
- safety
- reliability
- costs.

For these applications reliability is more important than accuracy. If a train system is to depend on GNSS signals it must be confident that the signal is correct at all times. As in all transport monitoring and navigation, system failures can have disastrous consequences. High reliability and integrity monitoring is therefore important.

3.2 Level of adoption

Precise positioning using augmented positioning is currently in use for surveying the railways, and will continue for at least 10 years (an estimate of the time to survey all existing track around Australia). Major surveying exercises are currently underway in Sydney and on the interstate tracks. Other jurisdictions will need to undertake this task prior to installing advanced train protection and control systems (not likely before 2017).

We have estimated that the ATMS system described above will have been introduced on the ARTC network by 2020. There will be advantages in capacity (more trains on a given track, hence postponement of investment in new infrastructure), reliability (hence stronger competition with other modes) and safety, as well as substantial cost savings in not having to maintain a traditional signal system.

3.3 In-cab signalling – productivity estimate

The ATMS in-cab signalling system would improve the efficiency of long distance train operation, eliminate expenditure on signal inspections, maintenance and renewal, and allow some investments in increased infrastructure capacity (e.g. extra lines or passing loops) to be deferred. The cost of ATMS would be significantly lower than the costs saved.

Augmented GNSS could be an enabling service for ATMS providing greater accuracy but, as mentioned above, high levels of reliability of position information. One area where augmented GNSS cannot at the present time provide such service is in tunnels. However the development of localised non-satellite dependent positioning technology that is compatible with GNSS signals offers some promise of a solution to this problem (see discussion in section 2.1.2 above).

No study has been published on the estimated size of the benefits a rough estimate based on partial industry information and ACIL Allen assumptions is a productivity improvement of 5% (high scenario) and 2% (low scenario). This would apply to approximately 25% of the rail sector, being the part controlled by the ARTC (interstate and Hunter Valley lines) – hence an average productivity improvement for the sector or 1.25% (high) and 0.5% (low). This does not allow for safety or reliability benefits, nor for longer term operational improvements made possible by the new technology.

ETCS (especially more advanced versions of the European system) would have similar improvements for urban railways, but they are not included as the European technology is not dependent on GNSS.

4 Productivity and economic impacts

Evidence from case studies and on levels of adoption were first used to estimate the potential impact on productivity and cost savings in the rail sector as at 2012 and the potential in 2020. These estimates were then used with estimates from other sectors to calculate the economy wide impacts of precise positioning for Australia as a whole.

4.1 Direct productivity impacts in the rail sector

The estimates of cost savings from the ATMS installed by ARTC and as discussed in Section 3.33.3 are shown in Table 1. ATMS can theoretically operate with signalling infrastructure and track circuits it could be more efficiently provided by augmented GNSS if it were available. Augmented GNSS is of course used in surveying track.

The table shows accumulated benefits in lower costs of between $1.8 million and $3.4 million in 2012 attributable to the use of precise GNSS in surveying track and rail infrastructure. This rises to benefits of between $9.5 million and $10.1 million by 2020 based on installation of ATMS on ARTC lines by 2020. The high case includes ARTC using Augmented GNSS also on dedicated mining rail lines.

Benefits in 2020 would be significantly higher if the metropolitan rail authorities adopted augmented GNSS for train control and monitoring. However as discussed in this report, the metropolitan authorities appear to be locked in to alternative approaches under the European ETCS technologies.

Table 1 **Estimate of benefits and productivity improvement in the rail sector**

	Description	Impact on costs	Percentage of value of production in sector	Impact on costs	Percentage of value of production in sector
		Low case	Low case	High case	High case
2012					
Precise GNSS use in surveying track and locating infrastructure	Estimate based on use of precise positioning in surveying rail track. Assumes 0.1% productivity with 20 % adoption for the low case and 0.15 per cent productivity improvement and 25% adoption for the high case.	$1,816,514	0.015%	$3,405,964	0.028%
2020					
Automated train management system for ARTC and dedicated mining industry infrastructure	Estimate based on assumption that ARTC ATMS achieves 0.3 % productivity improvement on its long distance lines . ARTC assets equivalent to 35 % adoption across the rail sector.	$9,536,700	0.080%	$10,081,654	0.084%

Note: Based on case study of ARTC ATMS and assumptions on adoption discussed in the text
Data source: ACIL Allen

4.2 Impact on sector output

The productivity impacts summarised in **Error! Reference source not found.** were used as inputs to ACIL Allen's Computable General Equilibrium (CGE) model, Tasman Global[2], to estimate the impact 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[3].

The results from this modelling for output of rail sector are shown in Table 2.

Table 2 **Impacts on output**

		Low case	High case	Low case	High case
		2012	2012	2020	2020
Increase in output	$ million	1	3	10	12
Percentage of total output		0.1%	0.2%	0.3%	0.5%

Note:
Data source: ACIL Allen modelling

The results for 2012 are not significant reflecting only the impact of augmented GNSS on track surveying.

The results for 2020 are more significant reflecting in part the benefits of ATMS for used in long distance rail operations. These results suggest that

[2] See overview report for a full description of the CGE modelling approach,

[3] Note that the productivity shocks for other sectors discussed in this report were also entered into the model at the same time.

output in the sector could be up to $12 million higher than it might otherwise be without greater use of the technology. This still only represents around 0.1 per cent of the output of the rail sector as a whole.

These results could be higher if metropolitan systems adopted ATMS systems. However to utilise augmented GNSS, there would need to be further development of localised GNSS compatible positioning systems for use in tunnels. There is no technology currently available to do this task.

Appendix A Case studies

A.1 RailCorp (Sydney Rail)

RailCorp uses high resolution GNSS for surveying track, and benefits from the efficiencies created by high resolution positioning. Accurate location and time-stamping of GNSS data are important where the RailCorp test trains are recording images of line side track infrastructure.

RailCorp has opted for ETCS as its train protection and control system. This system uses balises mounted between railway tracks to provide location information and movement authorities. Low-resolution GPS sensors are fitted on most trains. This will be used for backup and verification purposes, as well as asset location.

Apart from surveying for track maintenance, there are few benefits to high resolution GNSS in train operations on RailCorp's passenger networks.

A.1.1 Background

The ETCS integration manager at RailCorp (soon to be Sydney Trains) was interviewed.

RailCorp is investing in improved train safety systems. RailCorp has opted to purchase an established system called European Train Control Systems (ETCS). There are different levels of ETCS and RailCorp is opting for the lowest level – Level 1 with an option to upgrade to the more beneficial ETCS Level 2 in the future.

ETCS Level 1 links to existing signalling systems, and train positioning and movement authorities are relayed to an on-board computer and then to the drivers in-cab systems as trains pass over transponders or 'balises' mounted between the tracks. The on-board computer continuously monitors and calculates the maximum speed and the braking curve from these data. Because of the spot transmission of data, the train must travel over the balise beacon to obtain the next movement authority.

ETCS improves safety because it does not allow a train to pass a signal at danger. Balises are placed at locations that will allow sufficient braking distance as the train approaches the signal. Between two balises the train continues to determine its position via sensors (axle transducers, accelerometer, etc.). ETCS Level 1 provides some additional track capacity because clearances are not required beyond signals – at the moment some track is kept clear after a signal in case a train overruns it – in the case of junctions this can impact network capacity significantly. ETCS Level 1 means this overlap is no longer required.

ETCS Level 2 is a digital radio-based signal and train protection system. Movement authority and other signal aspects are displayed on the in-cab systems to the driver. It is therefore possible to dispense with trackside signalling. All trains automatically report their exact position and direction of travel to the Radio Block Centre (RBC) at regular intervals. Train movements are monitored continually by the radio block centre. The movement authority is transmitted to the vehicle continuously via GSM-R together with speed information and route data. As with ETCS Level 1, the balises are used as passive positioning beacons. Between two positioning beacons the train continues to determine its position via sensors and the positioning beacons are used in this case as reference points for correcting distance measurement errors. The on-board computer continuously monitors the transferred data and the maximum permissible speed.

ETCS is an old technology developed before accurate GPS was widely and cost-effectively available. It is, however an established technology with multiple suppliers and it is relatively cheap. There seems to be no intention to replace balises as the positioning device. Balises need to be placed on the track, and the ability to have short headways depends on the distance between balises. These balises need checking, maintenance and renewal over time. They are clearly a technology more suitable for urban networks with many signals over hundreds of kilometres of track, but they are less suitable for long-distance running and single line track, as in the case of ARTC (above).

A.1.2 ETCS use of high resolution positioning

In order to implement ETCS the position of track, signals, and the placement of balises needs to be known exactly. The ETCS design needs to know the location of signals, limits of authority and the centre line of the train. The required accuracy is within 1 metre. For this purpose RailCorp is surveying its existing track. New track installations are already recorded to very high levels of accuracy (thanks in part to modern GPS use), but older sections of track were recorded with less precision and a program is underway to rectify this.

For the surveying of track RailCorp is now using Oxford Technologies inertial navigation boxes mounted on test trains (these are GPS-integrated Inertial Measurement Units or IMUs). They need the IMUs because of passage through tunnels. The inertial positioning equipment also calculates the gradient with more accuracy than the GPS. RailCorp use Omnistar XP for precise GPS positioning – this is because the Oxford Technologies box can use Omnistar data. The average accuracy is within 15cm. 2-3 runs of recording are undertaken to verify measurements.

The track surveying project is expected to take 10 years to complete. It is starting from the edge of the network, moving in to the centre of the city. RailCorp already has a dedicated site surveying team who can measure to within 1cm accuracy. This team is usually dispatched to new site installations. They cost the company some $16 million per annum.

If RailCorp were not using Omnistar they would have to use traditional surveying methods, which would require much more labour, manual inputting and with greater error rates.

The application of ETCS requires significant investment. For the survey RailCorp is using electric test trains fitted with ATP equipment, GPS antennae and GPS inertial measurement units (IMUs). The IMUs cost some $60,000 with an additional $10,000 to fit them.

These trains take line scan pictures at 1,000 lines per second from the side of the train, building up a precise 3-D picture of the track and trackside assets. This is mapped to GNSS locations within 1cm accuracy. Accurate recording of GNSS timestamp is necessary to align the pictures to the location. These cameras cost $2,000-3,000 each.

A.1.3 GNSS uses in maintenance

RailCorp has commissioned 3 new track-recording vehicles which will do weekly surveys of top, twist, gauge, damaged track, and other maintenance tests. Typically these do not need high resolution GNSS as maintenance crews can locate the issues when given locational coordinates within a few metres. The track-recording vehicles will use survey geometry for baseline which is within 2cm of accuracy.

A.1.4 Other GNSS uses at RailCorp

Country trains in NSW and Waratahs in Sydney have GPS locators fitted on them for information on train location, but there is little need for accuracy. The country lines are not heavily trafficked.

Passenger information in Sydney displays pick up train location information based on track circuits/signalling infrastructure. Hence, the time until the arrival of the next train is measured as a standard time from the last occupied track section. GPS could be used for this, but adds little benefit.

A.2 Rio Tinto Iron Ore - Rail

Rio Tinto manages about 1,700 kilometres of track. There are 150 locomotives, including 8 maintenance vehicles, 8 bankers and 35 trains with 240 wagons per train. About 10 locomotives per year are being added to deal with volume growth. Train lengths are typically 3 kilometres long. Train lengths up to 7 kilometres have been seen in the Pilbara. Trains operate with 20-25 minutes headway. There is 200-300 kilometres of dual track at the most congested sections (typically the approach to port).

There are a number of useful GNSS applications, but none require high precision GNSS.

Train location is currently determined using signalling infrastructure and track circuits. Ultimately, this is nineteenth century technology[4]. The information that is gathered by this system is that it took several minutes for a train to clear a certain section of line. If the train encounters a delay it is not known where on the line segment this happens. More recently GNSS recording of the journey has provided additional useful data.

Rio Tinto trains use Automatic Train Protection (ATP). In July 2012 Ansaldo STS Australia was awarded a A$317 million contract to develop and deliver an automated train management system for Rio Tinto's iron ore rail network in Western Australia. The ATP system is expected to be finalized in 2015, and is intended to improve flexibility and capacity on Rio Tinto Iron Ore's mining rail network, it is likely to include GNSS. When the signalling system is implemented, Rio Tinto will be able to use driverless trains to transport iron ore on its 1,700km rail network in the Pilbara region.

A.2.1 GNSS application by Rio Tinto

GNSS is used to monitor the progress of trains between mines and port to improve asset efficiency and planning. Rio Tinto now uses GPS records of train movement to map the journeys and record delays and bottlenecks.

The past system was based driver recall – where he has to log any delays after a journey is completed. The recall method was performed by train control showing the driver a record of their train graphs and asking the driver to explain delays – this system caused a number of disputes between drivers and train controllers. GNSS records are considered more reliable and eliminate disagreements.

GNSS is also used to track assets. Rio Tinto records the turnaround time for assets, so timing the time taken to unload a payload, move to the yard, refuel, perform maintenance checks, return to a mine, load, and return to port. Minimising non-productive time is key to efficient asset use.

Sometimes locomotives are left in the yard and forgotten about. Given that each locomotive costs $3-$7 million this is an expensive waste of assets. By recording the location and movement of assets Rio Tinto hopes to optimise their utilisation.

Standard GPS doesn't identify location very well in the yard because of bounce off the metal structures. Differential GPS would fix this. The cost to implement high resolution GPS in the past has been prohibitive – 'Blackbox' pricing was $3,300 per annum per locomotive plus operating costs. With 140-150 locomotives this was approximately $0.5 million per annum more than standards GPS for little gain. Rio Tinto is adding some 10 locomotives per annum to its fleet so this cost would escalate.

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[4] The failsafe track circuit was invented in 1872 by William Robinson

When recording the movement of locomotives in transit location information is sent every 5 minutes. This is sufficient for asset management purposes. The first time that Rio undertook this exercise they sent information from 50 locomotives much more frequently and its first bill was in excess of $1 million.

Rio experienced some issues arising from inconsistent time stamps on stand-alone GNSS data. A frustration is that sometimes there are no GNSS changes and the train appears stationary, then there is a jump in location when all the data arrive at once. Precise positioning GNSS would address this problem.

A.2.2 Other GNSS uses

Rio Tinto is incorporating driverless trains and also fuel-saving software. These will both use GNSS locational information, but again will not require high resolution positioning.

Although not identified by Vanessa during the interview, it is possible that more advanced train protection and control applications may, in the future, require high-precision records of the location of track and signals.

A.2.3 Conclusion

The key issue for Rio Tinto was the cost of GNSS data. High frequency and high-precision uses were not taken up by Rio Tinto because of cost. In the mines there are applications of high-resolution positioning, but they are less important in the rail side of the business, which works on simple rail networks and very long trains.

If augmented GNSS were used it could be used for time stamping of train location as part of an ATMS. However our advice was that this alone is not likely to be sufficient justification for use of augmented GNSS.

A.3 Asciano

The Manager of Strategy and Infrastructure Planning at Asciano identified a number of GNSS uses in Asciano, and the benefits from GNSS use. In Asciano's rail operations there were no requirements for high-precision GNSS at this time. The overriding concern was integrity.

A.3.1 GNSS use in terminals

Asciano uses high-precision GPS in automated stevedoring through its Patrick subsidiary located at Port Botany. Precision is required to the millimetre and GNSS is augmented by radar positioning. Had high-precision GNSS been available ten years ago perhaps this would be the sole positioning system in use. Port case studies have been discussed in the associated transport report.

Asciano operates rail line haul and terminal operations. The terminal operations could conceivably be automated in the long run, but they are more messy than port stevedoring. At ports there are fenced off areas where personnel are not allowed to enter. In terminals there are trucks arriving late with containers, and so more judgement is required in loading the train. The movement of trucks makes the set-up more fluid than stevedoring operations.

Trains are also loaded to a complex plan with rules for dangerous goods, refrigerated containers, double stacking (heavier boxes and boxes with a minimum structural integrity on the bottom).

Asciano uses GNSS to monitor the movement of train loaders (fork lift trucks). This is used to determine whether train loaders are taking efficient routes to load the train or whether they are making excessive movements up and down the train.

A.3.2 GNSS use in fuel economy software

The difference in fuel use between Asciano's best and worst drivers (from a fuel economy point of view) can be significant. A key requirement for optimised fuel consumption is to minimise the acceleration and to minimise braking by using the natural topography. This approach is been applied in road freight in Europe using the European Geostationary Navigation Overlay Service (EGNOS)[5]. This is not an easy task when the driver has three locomotives pulling 1200-1700 metres of trailing wagons carrying thousands of tonnes of goods.

Software such as 'Leader' and 'Freightmiser' has been developed to optimise the train speed and acceleration based on a digital map of the route including gradients and curves, the location of signals and the location of the locomotives as well as incorporating information on the consist that the locomotives are pulling and the time at which the goods need to arrive.

Typically these systems provide recommended speeds and acceleration/braking advice to drivers on an in-cab display, they require positional information and the more accurate this is, the better the advice that they can provide to drivers.

The accuracy of the information needs to be within 100 metres of actual position. The integrity of the system is not vital because this is not a safety system – it improves the efficiency of the journey.

Freightmiser's marketing material indicates that a 10% increase in fuel efficiency could lead to a $100,000 saving per locomotive per annum (dependent on fuel price assumptions, operation between Melbourne and Perth and whether this fuel saving would, on average, be achieved).

Freightmiser is used by Asciano on its east-west route, but will eventually be rolled out to all intermodal and bulk haulage operations. Asciano's intermodal

[5] EGNOS is a Space Based Augmentation System (SBAS). EGNOS and Galileo are now part of Europe's GNSS programmes managed by the European Commission.

fleet is 350 locomotives. This could generate savings of $35 million per annum. If the same benefits accrued to QR National's and SCT's fleet then the national savings could be in the order of $5 million per annum. There would also be significant benefits in the use of this software in mining rail applications.

A.4 Productivity impacts – high resolution positioning

This section assesses the productivity impacts of high resolution positioning in the rail sector. They are relatively minor compared with the impact of in-cab signalling (which does not require high resolution) discussed in the main body of the paper, and are not included in the overall productivity estimate.

A.4.1 RailCorp and ARTC's use of high resolution GNSS

High resolution GNSS is used in surveying applications. This is covered in a specific case study on surveying, and to separately include this as a productivity impact in the rail sector is likely to lead to double counting.

In the case of ARTC and RailCorp high-resolution surveying would create a significant cost saving from avoiding the need to re-survey to resolve discrepancies.

A.4.2 Improving the efficiency of train loading

Precise positioning is not needed to monitor the movement of fork-lift drivers when loading trains, although vertical positioning accuracy and high levels of integrity would be beneficial. There are no gains expected from high-resolution positioning for general train loading. This differs to some extent to the use of augmented GNSS in locating and managing containers operations at ports.

A.4.3 Improving the efficiency of locomotive use in the mines

High resolution GNSS is generally not needed to locate locomotives in yards as the locomotives are under close supervision by operators. If it were to be used in shunting yards it would require augmentation to avoid errors introduced by signal bounce from the steel structures surrounding the locomotives.

It could be used for better management of assets en route. If asset location can increase the average use of assets by, say, 5% then at a new asset value of $5 million, instead of 10 new locomotives every year (20 every two years), then perhaps only 19 new locomotives would be needed every two years. This would save an ongoing cost of roughly $2.5 million per annum. There would also be a one-off benefit of a 5% efficiency gain on the fleet of 150 locomotives – if the average asset value is assumed to be $4 million then 5% additional productivity could be valued at $30 million to Rio Tinto.

Similar (indeed, larger) gains could be obtained at BHP Billiton facilities. Again, it is unlikely that high resolution services would be necessary.

A.4.4 Improving the performance of driver optimisation software

If improved resolution and higher integrity GNSS could improve the efficiency of Freightmiser by 1% then this would create estimated benefits of up to $350,000 per annum to Asciano.

If the same benefits accrued to QR National's and SCT's fleet then the national savings could be some $0.5 million per annum. There would also be similar scales of gain to mining companies who run their own trains on their lines.

This would also reduce greenhouse gas emissions from rail transport by approximately 0.1%.

Appendix B Acronyms

Acronym	Meaning
ATMS	Automated Train Management System
ATP	Automatic Train Protection
ATRC	Australian Rail Track Corporation
ETCS	European Train Control System
GNSS	Global Satellite Navigation Systems
GPS	Global Positioning System
IMU	Inertial Measurement Units
PNT	Positional, navigational and timing
RBC	Radio Block Centre

Appendix C References

Harcombe, P. (2012). Sydney Satellites. *Spatial@gov*. Sydney: NSW Land and Property Information.

Lateral Economics. (January 2009). *Nation Building for the Information Age*. Canberra: Lateral Economics.

Leica Geosystems. (August 2012). *Leica Jigsaw Positioning System using Locata Technology*. Leica Geosystems.

UN Office for Outer Space Affairs. (2010). *Current and Planned Global and Regional Navigational Satellite Syetems and Satellite-based Augmentation Systems*. New York: United Nations.

Precise positioning services in the maritime sector

An estimate of the economic and social benefits of the use of augmented positioning services in the maritime sector

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

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Executive summary

The maritime sector relies on accurate positioning for safe navigation and operation of ships in confined waters, in environmentally sensitive areas and for operations in the offshore oil and gas sector.

Position accuracy requirements vary according to the specific circumstances. In general position accuracy required is:

- 10 metre horizontal accuracy for general navigation
- 2.5 metres in ports
- 10 cm for marine engineering, dredging and hydrographic mapping
- 1 metre for tugs, cable, pipe laying and aids to navigation
- 1 cm for automatic docking.

Integrity is as important as position. Navigation standards specify a time to alarm of 10 seconds.

Positioning information from Global Navigation Satellite System (GNSS) is used in the current generation of shipboard devices such as the Automatic Identification System (AIS) and in Electronic Chart Display and Information Systems (ECDIS). GNSS is also used in many cases as the sole accurate timing reference on board a ship. These systems will be key elements of an e-navigation concept that international and national regulatory authorities are developing to further improve the safety of marine navigation.

The International Maritime Organization issued minimum maritime user requirements for positioning for marine navigation. To meet these requirements, augmented GNSS is required in ports and port operations, for dredging and cable laying, construction works and for marine aids to navigation (IMO, 2001). It is used by marine pilots for navigation in ports, docking activities and in under keel clearance systems. It is also used in the conduct of hydrographic and geophysical surveys. The offshore oil and gas sector uses GNSS for positioning work vessels and mobile drilling rigs.

Given the regulatory requirements for positional accuracy and time-to-alarm (integrity monitoring) it is difficult to envisage marine navigation without augmented GNSS for the above operations.

The economic and social benefits of navigation technologies relying on augmented GNSS include:

- Reducing the frequency of groundings in Torres Strait saving between $0.6 million and $0.8 million per year on average in clean up and salvage costs.
- Under keel clearance management systems to be introduced in 2013 which could deliver benefits of between $10 million and $13 million per year to the shipping industry by 2020.

- Savings in port infrastructure from improved channel tolerances reducing the cost of buoys and dredging by around $1.8 million in 2012 and $2 million in 2020.
- reduced environmental risks from oil spills estimated of around $1.9 million in 2012 and $3.4 million in 2020.
- Around 10 per cent saving in lost down time for geophysical surveys worth around $5 million in 2012 and $10 million in 2020.

The total amount attributable to the maritime sector total to around $4.2 million in 2012 and 16.2 million by 2020. These amounts represent around 0.07 per cent and 0.30 per cent of total output from the maritime sector. The savings in seismic surveying have been attributed to the mining sector for the economic analysis.

Key findings

- GNSS has become a component of position fixing for ships and will improve, replace or supplement existing position fixing systems some of which have shortcomings in regard to integrity, availability, control and system life expectancy.
- Augmented GNSS is used in many operations including navigation in ports and environmentally sensitive areas, operation of tugs, dredging and construction works, hydrographic geotechnical surveys and for offshore oil and gas operations.
- The maritime sector draws on all types of augmentation systems including the Differential GPS service provided by the Australian Maritime Safety Authority, RTK stand-alone, CORS networks where available and wide area space based services.
- There are a wide range of economic and social benefits that arise from the use of augmented GNSS in the maritime sector. The value of safety of life at sea and the protection of the marine environment against oil spills is very significant.
- The shipping industry is moving towards an e-navigation concept where a range of electronic and radio navigation technologies will provide safe and secure support for navigation by mariners. Augmented GNSS is one of the supporting technologies for e-navigation.

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. This report addresses the aviation sector.

The purpose of this report is to provide an understanding of the economic and social benefits of precise positioning information within the aviation 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 maritime sector

The maritime sector includes commercial ocean and coastal shipping (including the cruise ship sector, which is seeing growth in many parts of the world, including Australia), stevedoring, port and water transport operations, offshore construction and maintenance, and marine activities associated with geophysics, oil and gas extraction[1].

The sector makes a significant contribution to the Australian economy through carriage of Australian trade. In 2010-12 Australia's exports by sea were worth $222.6 billion and grew at an annual average growth of 10.7 per cent over the previous five years. Australia's imports by sea were worth $160.9 billion and increased at an annual average rate of 5.5 per cent over the previous five years (BITRE, 2012).

Important sub-sectors of the shipping industry also operate in areas of high environmental value. The Great Barrier Reef Marine Park and Torres Strait are important sea lanes for transport of bulk commodities, petroleum, containerised goods and for tourism. Safety of navigation in the environmentally sensitive and navigationally challenging waters of the Great Barrier Reef and Torres Strait is critical.

3 Positioning requirements in the maritime sector

The maritime industry is truly an international one and where requirements for the safety of navigation are established by the International Maritime Organization (IMO) of which Australia is a founding member. Member States

[1] The maritime sector as described above is captured in Divisions B (Mining) and I (transport) in the Australian and New Zealand Standard Industry Classification.

of the IMO have recognised the need for a civil and internationally controlled global navigational satellite system (GNSS) provision of navigational position-fixing for maritime purposes throughout the world for general navigation and for navigation in restricted waters such as ports and passages (International Maritime Organization, 2001).

The IMO has recognised that GNSS will improve, replace or supplement existing position fixing systems some of which have shortcomings in regard to integrity, availability, control and system life expectancy.

The requirements for position accuracy, integrity and service levels vary according to the type of marine activity involved. Reliability and integrity are also important criteria for safety of navigation. Integrity is the ability to provide users with warnings within a specified time when the system should not be used for navigation[2]. Alert limit is the magnitude of positional error before a warning is issued. A summary of these requirements set by the IMO is outlined below and a full description is provided in section Appendix C.

The IMO requirements for general maritime navigation are 10 metre horizontal accuracy and 1 metre in ports. A more important criterion is integrity where the time to alarm for an outage is 10 seconds and the alert limit is 25 metres for general navigation and 2.5 metres for ports. Accuracy for activities such as docking is generally more demanding. The horizontal accuracy required for automatic docking is 1 cm. Accuracy requirements for tugs and icebreakers is 1 metre. In each of these cases the integrity requirements are a time to alarm of 10 seconds and an alert limit of 2.5 metres.

Horizontal accuracy for marine engineering is 10 cm for dredging and construction works and 1 metre for cable and pipeline laying and for management of aids to navigation. Integrity requirements for these activities are 10 seconds time to alarm with alert limits of 25 cm for dredging and construction works and 2.5 metres for cable laying and management of aids to navigation.

Hydrographic mapping also requires accuracies of around 10 cm.

[2] Integrity monitoring is the process of determining whether the system performance) allow use for navigation purposes. Overall GNSS system integrity is described by three parameters: the threshold value or alert limit, the time to alarm and the integrity risk. The output of integrity monitoring is that individual (erroneous) observations or the overall GNSS system cannot be used for navigation (International Maritime Organization, 2001).

4 The value of applications in general shipping

4.1 Economic Benefits

Augmented GNSS supports a range of technologies, service and systems that deliver benefits in the maritime sector. This includes reducing maritime accidents and groundings, lowering environmental risk factors, reducing the incidents and risks of oil spills and reducing the infrastructure costs for ports.

Safety of navigation depends on the reliability of human decision making supported by aids to navigation. Accidents and groundings potentially endanger the environment and also create costs for administrations and the industry in clean-up of any resultant pollution (e.g. oil spills) or management of incidents when they arise.

The cost of oil spills varies. Recent evidence in Australia demonstrated that a significant oil spill could cause costs in salvage and clean-up of around $30 million[3]. A serious oil spill would be catastrophic if it occurred in the Great Barrier Reef Marine Park.

The Great Barrier Reef region supports a variety of commercial and recreational activities including fishing, tourism and recreation worth in excess of $5 billion per annum to the Australian economy. The shipping of bulk cargoes and petroleum transport through the reef accounts for some $17 billion of Australia's export trade. (Access Economics, 2005). With the commencement of LNG shipping from Gladstone in 2014 this value will increase significantly.

This economic activity depends on safe shipping operations in the Great Barrier Reef Marine Park as well as Torres Strait. Augmented GNSS contributes to safer shipping operations in these waters and plays an important supporting role underpinning these economic activities. It does so in many ways.

For example, a study Under Keel Clearance (UKC) commissioned by the Australian Maritime Safety Authority in 2008 examined the use of UKC management systems in the Torres Strait and Great Barrier Reef. UKC systems in this area also rely on augmented GNSS. This was shown to deliver potential savings to the bulk shipping sector of between $10 million and $13 million per year (Thomson Clarke, March 2007). Augmented GNSS plays a supporting role with portable pilot units for UKC management systems in these areas.

Augmented GNSS can in some cases deliver lower costs for port operations. An unpublished study prepared for the Queensland Department of Natural

[3] See later discussion in section 5.3.

Resources and Water in 2007 reported that augmented GNSS pilotage systems and improved channel tolerances had reduced the need for buoys in a major Queensland coal port, saving around $4 million in capital costs. It would be reasonable to assume that other similar ports are also realising benefits. Assuming similar savings are possible in around 5 similar ports in Australia this could save around $1.8 million per annum in depreciation and maintenance.

4.2 Navigation and GNSS

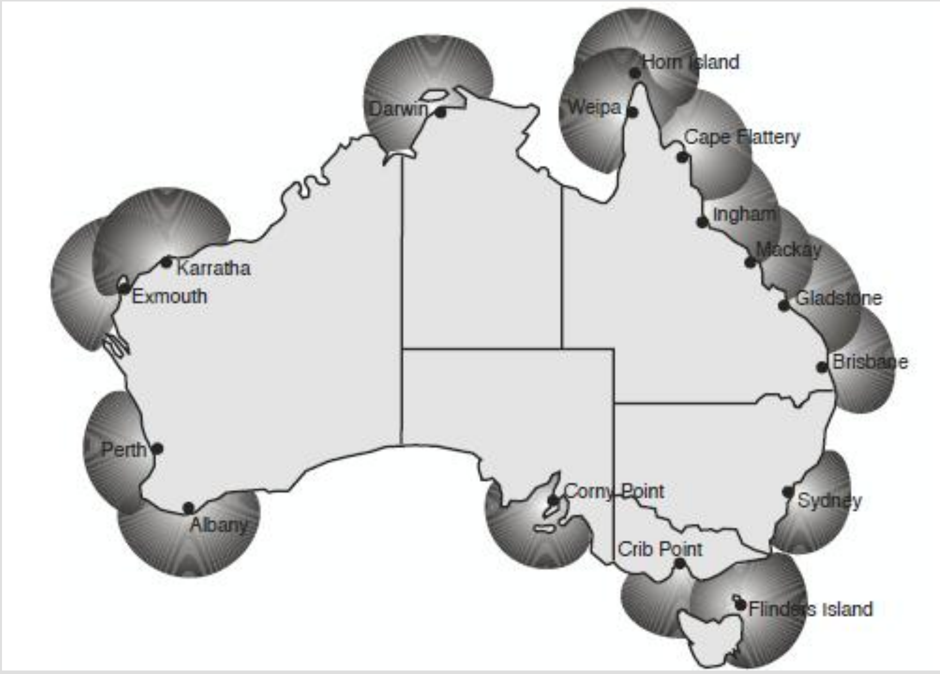
The task of marine navigation has been subject to considerable technological change over the past decades. Mariners rely on several sources of information to locate their position. This includes celestial navigation, light houses, radar and radar enhancers, radionavigation systems and GNSS. Celestial navigation has more or less been replaced by GNSS. The shipping industry has become increasingly dependent on GNSS over the past decade with GNSS becoming the primary means of position determination (AMSA, March 2012).

Positioning and timing from GNSS are used in the current generation of shipboard devises such as Automatic Identification Systems (AIS) and Electronic Chart Display and Information Systems (ECDIS). Augmented GNSS is also used in many cases as the sole, accurate timing reference on board ships. Augmented GNSS is required in any area discussed above where position accuracy of 1 metre or less are required.

The Australian Maritime Safety Authority manages a system of sixteen Differential GPS (DGPS) beacons around the Australian coast to provide augmented GNSS signals (see Box 1). Commercial services are also used by marine pilots as discussed in Section 4.3 below.

Box 1 **AMSA's DGPS service**

AMSA's DGPS service provides a network of radio beacons that improve the accuracy and integrity of the GPS signal around selected areas of the Australian coast. The service is primarily intended for levy-paying commercial shipping.



The service has been proven to provide accuracy of between 2 to 4 metres for most circumstances compared with stand-alone GPS accuracy of between 13 to 22 metres. Integrity monitoring is an important feature of DGPS. The stations test for GPS signals that are out of specification and immediately notify users to disregard the signal With DGPS the signal out warning occurs within a few seconds of a satellite becoming faulty. This could take up to 12 hours with stand-alone GPS.

Source: (AMSA, 2012)

The AMSA GNSS provides coverage of major ports and the Great Barrier Reef and Torres Strait. RTK and CORS services are also sometimes used in coastal applications for specialist surveying activities. These services, in conjunction with other navigation and vessel tracking systems, underpin safer navigation, lower risks of groundings and collisions and facilitate more efficient port operations. Economic benefits accrue from lower operating costs in ports, improved productivity in the ship operations and lower environmental damage costs.

To understand how these benefits arise, it is first necessary to first consider the framework within augmented GNSS relates to other navigation and monitoring systems in the maritime sector.

4.2.1 Electronic Chart Display Information Systems (ECDIS)

ECDIS represents one of the most significant changes in maritime navigation in recent years. The IMO has mandated carriage of EDCIS on larger passenger ships, tankers and cargo ships engaged on international voyages. The provision of accurate and reliable position, navigation and timing (PNT) is a core requirement for the operation of ECDIS.

Precise positioning provided by augmented GNSS signals is particularly important for use of ECDIS in marine sensitive areas such as the Great Barrier Reef and for port approaches and navigation in restricted areas. ECDIS systems can incorporate warning signals that are activated if a vessel ventures into dangerous waters. Such systems require reliable position accuracy and high levels of integrity that only augmented GNSS.

4.2.2 AIS

AIS is a ship-to-ship and ship-to-shore data exchange system that exchanges information on identity, position, course, speed and other ship information, automatically and continuously between mobile and fixed AIS stations. The IMO requires the majority of the international fleet to carry AIS and it is also increasingly being used by smaller commercial and recreational vessels.

AIS is being used for other applications as well including vessel tracking systems, as a further aid to navigation, for management of under keel clearance, assisting in responding to oil spills and for search and rescue operations. It is a framework that contributes to lowering the risk of maritime accidents and environmental damage.

AIS depends on reliable PNT[4] information for which the most cost effective technology is augmented GNSS[5].

4.3 Pilots

The most hazardous part of any ship's voyage is the transit through a port or an environmentally sensitive area. Within port limits, where the margins of safety are greatly reduced, the chances of collateral damage costs are very high. The added precision and integrity monitoring that DGPS provides is considered critical for the provision of safe pilotage with the use of PPU technology.

A growing trend is for pilots to use Portable Pilot Units (PPU) which increasingly use augmented (GNSS) (see Box 2). The increased accuracy is not necessarily used in a direct sense, (most pilots are looking out the window or over the side for the last few metres of positioning accuracy), but the biggest benefit for increased positional accuracy is through the consequent improvement in velocity, being a derivation of position changes over time. The more accurate the knowledge of position each second, the more accurate the knowledge of velocity will be.

[4] PNT stands for Position Navigation and Timing

[5] The alternative to augmented GNSS is highly accurate but expensive atomic clocks.

According to a survey of the Australian Marine Pilots Association and Marine Ports Australia, augmented GNSS is used by pilots in ports in Queensland, Port Philip Bay, Freemantle, Dampier, Port Headland, Flinders Ports, Albany and ports in Northern Tasmania. Some use the AMSA DGPS service while others use commercial services or establish their own reference stations[6].

This use is likely to increase as the technology of portable pilot systems improves and the requirement for safer navigation and applications such as under keel clearance management systems are introduced.

Box 2 **Portable pilot units**

Portable pilot units incorporating augmented GNSS capability are increasingly being used by marine pilots for navigation in ports and constrained waters and in the Great Barrier Reef Marine Park

Source: (Navicom Dynamics, 2013)

Economic value is created when accurate position information is added to the information in portable pilot units which supports better decision making in port manoeuvres, in environmentally sensitive areas and when docking.

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66 Personal communication

4.4 Under keel clearance

The economic benefits of under keel clearance were discussed previously. To ensure sufficient under keel clearances (UKC) of ships transiting Torres Strait, the current maximum draught for piloted ships is 12.2 metres. Ships with a draught of 12.2 metres are able to pass through Torres Strait within a tidal window on any day of the year whilst maintaining the required UKC. Tidal windows are restricted to periods around times of high water.

UKC management systems have been developed that provide more accurate information on under keel clearances that allow mariners to operate with smaller under keel clearances whilst at the same time maintaining an adequate safety margin. UKC systems require precise positioning and high levels of reliability. Augmented GNSS is used in the Portable Pilot Units that support UKC systems.

AMSA has introduced a UKC management system for use by coastal pilots on board ships transiting Torres Strait. The economic benefits have been outlined earlier in this report.

5 Monitoring and control

5.1 Benefits

Vessel Tracking Services (VTS) and Automated Ship Reporting have been important in improving the safety and reliability of ships sailing in Australian waters. This has delivered economic benefits to the shipping industry by reducing the risk of maritime accidents and groundings and reducing the risk of environmental damage from oil spills. They rely on augmented GNSS for sailing in most parts of Australian Coastal waters.

Since the introduction of the REEFVTS the average number of groundings in the Great Barrier Reef and Torres Strait has fallen from 1.42 per 10,000 transits to 0.15 groundings per 10,000 transits. This reduction is attributed to REEFVTS providing timely and accurate information to assist on-board decision making by the officers on the bridge (see Figure 1).

Box 3 **REEFVTS**

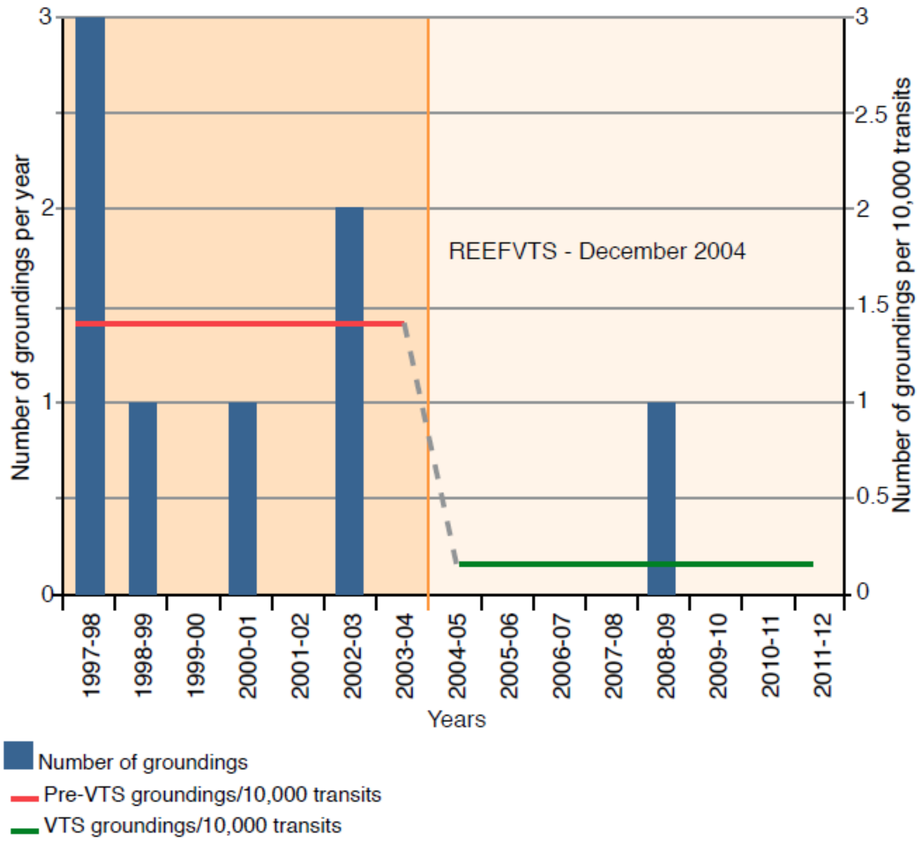
The Queensland and Australian Governments established REEFVTS in 2004. Its purpose is to:

- make navigation in Torres Strait and the inner route of the Great Barrier Reef safer by working with shipping to give better information on possible traffic conflicts and other navigational information
- minimise the risk of maritime accidents, and therefore avoid the pollution and damage which such accidents can cause to the marine environment in the Great Barrier Reef and Torres Strait
- respond quickly if a safety or pollution incident does occur.

REEFVTS is operated jointly by the Australian Maritime Safety Authority (AMSA) and Maritime Safety Queensland (MSQ). AMSA is an agency of the Commonwealth Government; MSQ is an agency of the Queensland State Government. REEFVTS operates 24 hours a day from the VTS Centre, situated at Townsville on the Queensland coast.

Source: (AMSA, July 2011)

Figure 1 **Groundings since the introduction of REEFVTS**

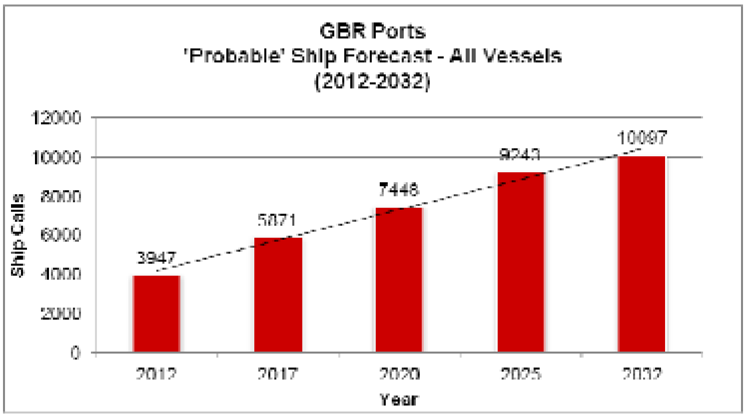


Data source: (AMSA, 2012)

In 2009-10, there were approximately 10,000 ship movements in the Great Barrier Reef involving some 3,500 ships[7]. The number of ships transiting the area is expected to increase at around 4 per cent per year as shown in Figure 2.

[7] Movement' meaning the passage of a ship to, from or between GBR ports, or on passage through the GBR region en route to or from ports outside of the GBR region.

Figure 2 **Estimates of vessel calling in regional ports.**



Data source: (PGM Environment, 2012)

The cost of groundings varies depending on the extent of damage. At a minimum costs are incurred by the shipping company in lost days and by the authorities who arrange towing and any clean-up. Charter rates for large bulk carriers are around $50,000 to 100,000 per day (HANSA, 2013).

The seriousness of groundings varies widely but if it is assumed that on average grounding might take a vessel out of action for between 3 and 10 days per grounding the introduction of the REEFVTS would have reduced the average annual cost of groundings by between $200,000 to $800,000 as a result of the introduction of REEFVTS. As mentioned earlier, REEFVTS is supported by the GNSS augmentation signal broadcast from the AMSA beacons in the Torres Strait.

A grounding or accident which involved an oil spill would have far more serious consequences.

5.2 Vessel Traffic Services (VTS)

Vessel Traffic Services (VTS) are shore-based systems which range from the provision of simple information messages to ships, such as the position of other traffic or meteorological hazard warnings, to extensive management of traffic within a port or waterway. They require accurate position information with high reliability. Generally, ships entering a VTS area report to the authorities, usually by radio, and may be tracked by the VTS using radar, Automated Identification System (AIS) and other technologies, most of which are supported by augmented GNSS.

The benefits VTS derive from the fact that it allows identification and monitoring of vessels, strategic planning of vessel movements and provision of navigational information and assistance. VTS can also assist in prevention of pollution and co-ordination of pollution/emergency response. VTS has the capability to interact and influence the decision-making processes on board ships. As such it reduces the potential for errors in navigation leading to incidents and accidents and helps manage the environmental risk associated with oil spills. As approximately 80% of maritime accidents can be attributed to the human factor, there is considerable benefit from interaction between the ship and VTS as an additional safeguard for safe navigation. (AMSA, July 2011) (IMO, 2009)

5.3 Automated ship reporting

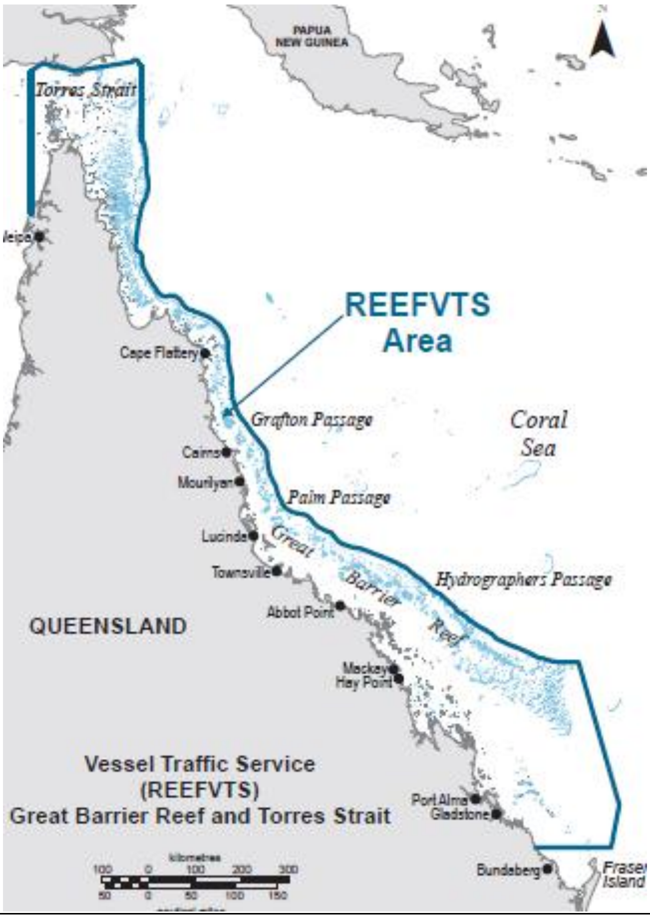
Automatic ship report (AIS) systems Australia produce significant economic benefits through safer shipping, lower numbers of groundings and lower risk of environmental damage from oil spills.

Automated ship reporting operates around the Australian coast providing AMSA with periodic updated reports of a vessels track and speed. The MASTREP system provides reports around the coast while the REEFREP monitors vessels travelling through the Great Barrier Reef and Torres Strait.

The AMSA DGPS service provides enhanced position accuracy and most importantly integrity monitoring of the GPS signal in the REEFVTS area to ensure that the ships are notified if the GPS signal is out of specification and should be disregarded. With the DGPS service these warnings are generated within a few seconds of a satellite becoming unhealthy.

The higher level of positional accuracy and performance integrity is critical for monitoring movements of ships through constrained shipping lanes and environmentally sensitive areas such as the Torres Strait and the Great Barrier Reef. Groundings and potential oil spills in the Great Barrier Reef area would have significant environmental and clean-up costs. Minimising the possibility of such events minimises related clean-up and compensation costs to industry and government and minimises environmental damage in a world heritage area which also supports an important tourism industry.

Figure 3 **REEfVTS area**



Data source: (AMSA, July 2011)

As discussed previously, the environmental costs of oil spills are extremely high in any area of Australia's coastal seas. Costs involve downtime of ships, the cost of clean-up, and the cost of towing if necessary. In addition there are significant environmental damage costs.

The grounding of the Shen Neng 1 in 2010 resulted in loss of about four metric tonnes of oil into the sea. The Shen Neng 1 did not break up and the spill was dispersed with chemicals. The incident MV Pacific Adventurer in Moreton Bay in 2009 however resulted in a more significant oil spill (around 270 tonnes) and clean-up costs of over $ 30 million. If such an event occurred in the Great Barrier Reef, the clean-up costs would have been significantly higher.

An assessment of the costs of oil spill risk in the Great Barrier Reef Marine Park was undertaken in 2011 by DNV. The assessment took into account the use of VTS, traffic separation schemes, double hull protection and compulsory pilotage (see section Appendix B). The net risk was assessed as $9.1 million per year and to increase to $17 million by 2020. The assessment assumed a 79 per cent growth in national traffic between 2011 and 2020 but did not include growth in shipments of LNG through the GBR Marine Park.

It would not be unreasonable to assume that this assessment would have been around 20 per cent higher without systems supported by augmented GNSS. This would imply a value of around $1.8 million in 2012 and $3.4 million in 2020.

6 Offshore oil and gas operations

6.1 Benefits

The use of augmented GNSS in bathymetry and in offshore oil and gas operations has multiple benefits. More accurate bathymetry improves marine charts and safety of navigation. Augmented GNSS enables more efficient and lower cost bathymetry compared to other methods.

Augmented GNSS also increases the efficiency of some offshore oil and gas operations. One large offshore as producer estimated that the use of augmented GNSS in survey operations saves around 10 per cent in lost downtime. This would be equivalent to annual savings of between $5 million and $10 million in savings per years.

Other benefits derive from the use of augmented GNSS in dynamic position of vessels and in positioning mobile oil drilling platforms.

6.1.1 GNSS in offshore oil and gas operations

Offshore oil and gas operations require positional accuracy for exploration, drilling, construction, production and operations. The operating environment is high risk and is generally in remote waters. The cost of accidents is high both in financial and environmental terms.

They also require precise positioning to locate mobile drilling rigs, to support survey and geotechnical vessels and to dynamically position vessels during construction and maintenance operations. This requires accuracy at the sub metre level and high levels of reliability and integrity.

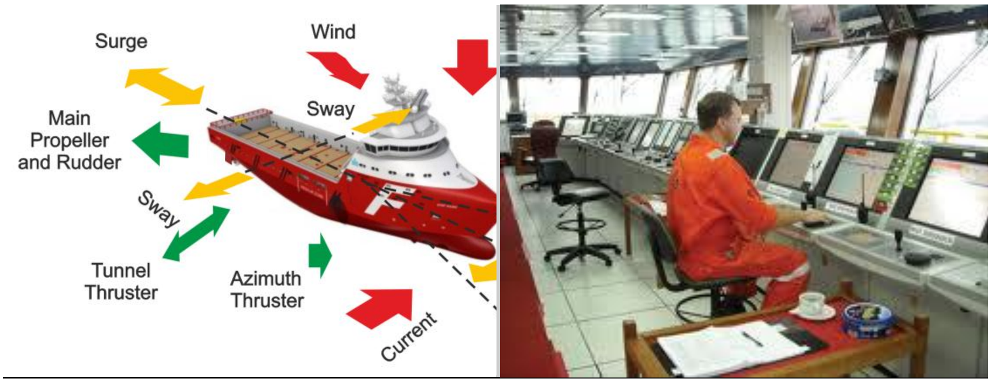
Augmented GNSS has become an enabling technology in conjunction with electronic and radio navigation systems and control systems for dynamic positioning of vessels, mobile drilling rigs and survey and geotechnical vessels.

6.2 Dynamic Positioning

Dynamic Positioning (DP) is a method for the station-keeping or precise positioning of special purpose marine vessels. A DP system seeks to maintain the vessel's position and orientation at a level of specified accuracy and reliability by compensating for the dynamic effect on the vessel of displacing forces such as wind, wave, and current (refer to figure 4). The core DP positioning technologies of augmented GNSS and inertial measurement units (IMU) are integrated with other sensors in a real-time navigation computer to provide precise and automated commands to the vessel's multi-directional thrusters.

In general, a DP-capable vessel can complete a work program more efficiently than a conventionally positioned vessel. It also minimises the potential for damage to the environment or sub-sea infrastructure from the use of anchors.

Figure 4 **Dynamic positioning**



Data source: Wordpress

A typical scenario where DP is used is a Diving Support Vessel that has to work on sub-sea infrastructure installed adjacent to an oil platform. The DP system allows the vessels to move efficiently around the platform, and any other exclusion zone, safely and efficiently and without the use of anchors and trailing mooring lines that increase the risk of entanglement. DP may also eliminate the need to install acoustic positioning units on the sea floor. The installation of anchors and acoustic systems is time consuming and has significant logistic and safety risks, and so in these situations DP has both cost and risk management benefits.

DP systems are increasingly used in offshore oil and gas operations off the Australian coast for the positioning of mobile drill rigs, survey and geotechnical vessels, tugs and platform service vessels where the ability to control the position and orientation of the vessel is mission critical.

6.3 Survey and geotechnical

6.3.1 Hydrographic surveys

Hydrographic surveys depend on augmented GNSS for coastal/port areas. The majority of the work uses RTK GNSS or post-processing, where infrastructure is available, to support this work to the required accuracy. Wide Area DGPS is used for offshore work[8].

With LIDAR (both for bathymetric and land) now being used extensively for coastal work, environmental modelling for climate change and flood

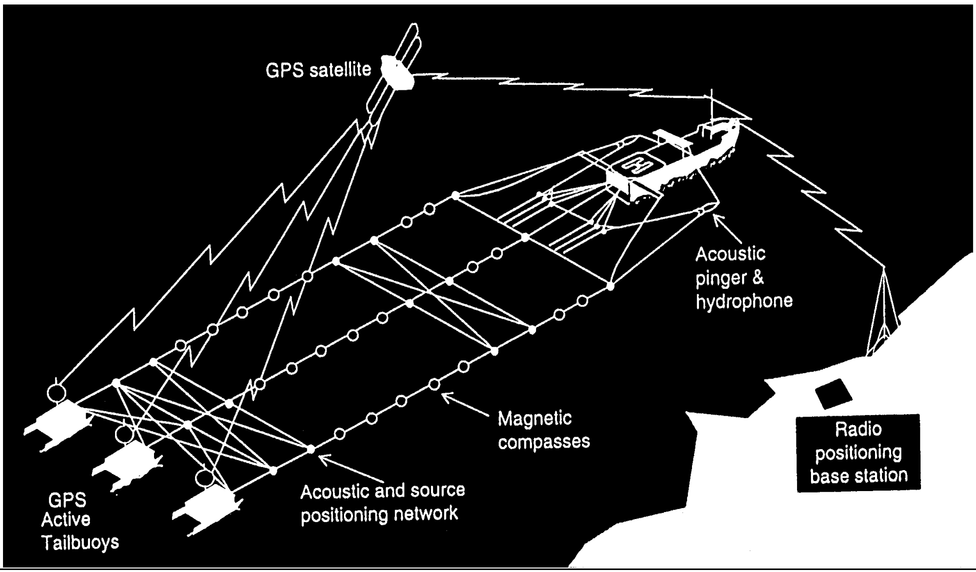
[8] Personal communication from the Australian Hydrographic Service.

management, there is an emerging need for a tool to allow better merging of bathymetry with land information in the intertidal zone. The key linking factor between these two is augmented GNSS. It is a common vertical reference datum that is used for both land and marine mapping. This is a future development requirement (Keysers, 2013).

6.3.2 Geotechnical surveys

The early stages of exploration for offshore oil and gas involve surveys run from specially equipped seismic survey vessels. These vessels broadcast sound waves that when reflected back from sedimentary layers beneath the seabed provide data that assists geologists interpret the sub-seabed geological structures (see Figure 5).

Figure 5 **Seismic survey**



Data source: Woodside

The track of the survey vessel must be known with high accuracy and reliability in order to map the results for subsequent analysis. If the survey vessel's position is not recorded correctly the resulting analysis can be degraded.

Augmented GNSS is used by these vessels to provide an accurate record of the survey tracks. Industry consultations indicated that the greater precision with augmented GNSS resulted in more accurate outcomes and better results than with stand-alone GNSS.

6.4 Mobile drilling rigs

Deepwater exploration for oil and gas is undertaken by mobile drilling rigs. These are large floating pontoons that can be towed from location to location. Once in position the drilling platform is anchored in place while drilling operations proceed.

Mobile drilling rigs require high levels of positioning precision both in terms of horizontal accuracy and reliability. Their location is important as drilling operations are directed from their platforms and high levels of certainty and precision are required to direct the drill lines and accurately record the location for analysis of results.

Stand-alone GNSS does not provide the level of positional accuracy or reliability and integrity for location of mobile drilling rigs. The alternative approach would involve additional set up costs to position the drilling rig prior to anchoring to the sea bed.

7 Future directions – e-navigation

The most recent developments under consideration by the Maritime Safety Committee of the IMO in its work on navigation, radio communications and search and rescue is the development of an e-navigation strategy. The aim of the e-navigation strategy is to integrate the existing and emerging navigation tools and in particular electronic tools including GNSS and augmented GNSS to enhance future navigation safety. ((IMO, July 2007).

This development recognises that the majority of collisions or groundings are caused by human error and the cost of these (to both companies and administrations) is rising each year (Lemon, 2010).

E-navigation has the potential to deliver improvements through the integration of ECDIS, GNSS, AIS and radar, along with improved links between ship and shore. Precise GNSS is a basic component of this technology mix in the areas identified earlier in this report.

7.1 Benefits

Augmented GNSS is an enabling technology that has a place in future e-navigation solutions. E-navigation systems in turn are an aid to navigation decision making by officers on the bridge. A search of literature did not identify any economic studies of the possible economic benefits of e-navigation. However one paper suggests e-navigation could improve the reliability of human decisions on the bridge by a factor of 10 (IMO, 2009). Better decisions reduce the risk of marine accidents, and oil spills. As discussed earlier the economic and environmental costs of oil spills can be extremely high.

8 Economic and social impacts

It is also difficult to envisage a maritime sector without augmented GNSS. The regulatory requirements for the use of augmented GNSS in navigation aids and with systems such as ECDIS, VTS and AIS, are established under an international framework. These requirements were introduced over the years in recognition of the economic and social values associated with safety of navigation.

Attribution of benefits arising from augmented GNSS must take into account the fact that it is an enabling technology in most cases incorporated into other navigation systems. The economic and social benefits include intangible but significant benefits from safety of life at sea, protection of the marine environment and in particular reducing the risk of maritime accidents and oil spills.

Direct economic benefits include reduced costs for the shipping industry from more efficient pilotage in ports and harbours, lower average annual cost of downtime from accidents, lower average costs of oil spills and support for trade conveyed by shipping through environmentally sensitive areas.

A list of potential economic and environmental benefits of applications in the maritime sector is provided in Table 1. These estimates represent only benefits that we have been able to quantify. They are therefore considered to be conservative.

Table 1 **Estimates of the benefits derived from navigation technologies dependent on augmented GNSS**

Sector	Application and benefit	2012	2020
Shipping industry	Reduced costs of maritime accidents.	Reduced costs of groundings. **$0.6 million** savings in lost time reported in Section 5.1.	Reduced costs of groundings. **$0.8 million** based on savings reported in section 5.1 Full development of e navigation is estimated to have the potential to Improve decision making on the bridge by a factor of 10. (Section 7.1).
	Greater shipping capacity through the Torres Strait with under keel clearance technologies	Not applicable in 2012.	**Between $10 million and $13 million per year** (Thomson Clarke, March 2007). Section 4.1.
Ports	More precise pilotage and improved channel tolerances reducing the cost of buoys and dredging.	Savings of around **$1.8 million** per year. (Section 4.1)	Benefits likely to grow slowly as demand on major ports increases with LNG and other minerals exports increase. Savings of **$2 million** per year assumed. (Section 4.1)
Offshore oil and gas industry	Lower costs in seismic surveys, positioning mobile drilling platforms and from dynamic positioning	**Savings of $5 million per year**.	**Savings of $10 million per year.**

Sector	Application and benefit	2012	2020
Fishing, tourism and resources industries	Improved safety in the Torres Strait and GBR marine park reduces risk of loss of income from maritime accidents, groundings and oil pollution and spills.	The value of augmented GNSS as a navigation support service for vessel track and VTS is in part in ensuring that this trade can continue.	Value of trade in the Torres Strait is likely to grow by at least 70 per cent by 2020 based on studies (Thomson Clarke, March 2007) (BITRE, 2012)
The environment	National Plan to Combat Pollution of the Sea by Oil and other Hazardous Materials. Established in 1975. (AMSA, October 2012)	Oil spill risk of **$1.8 mil**lion (ACIL Allen estimate based on impact of VTS on groundings). Section 5.3.	Oil spill risk of **$3.4 million** (ACIL Allen estimate based on impact of VTS on groundings). Section 5.3.
Total quantifiable benefits to shipping industry	All benefits apart from offshore geophysical surveys are attributable to the shipping industry. Geophysical surveys are reported in the mining sector.	Total quantifiable benefits identified above total around **$4.2 million**. This equivalent to around 0.07% of sector output.	Total quantifiable benefits identified above total around **$16.2 million**. This equivalent to around 0.30% of sector output.

Note: Estimates are based on studies and consultations with industry and government.

Data source: Data in the table is compiled from information included in the report.

The last row shows the benefits from applications of augmented GNSS that we consider can be attributed to the maritime sector. The last row shows that the total benefits are estimated to be around $4.2 million in 2012 and 16.2 million by 2020. These amounts represent around 0.07 per cent and 0.30 per cent of total output from the maritime sector.

The most value of augmented GNSS in the maritime sector is its contribution to safer navigation, improved safety of life at sea and protection of the marine environment. The value of the latter is difficult to estimate with certainty. However the potential social and environmental benefits are likely to be significantly higher than the direct economic benefits.

Appendix A Glossary of terms

Term	Meaning
AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
AUSVTS	Australian Vessel Traffic System
ECDIS	Electronic Charting and Display Information System
GBR	Great Barrier Reef
GNSS	Global Navigational Satellite System
GPS	Global Positioning System – originally the term for the US Navstar GNSS
IMO	International Maritime Organisation
PNT	Position Navigation and Timing
PPU	Portable Pilot Unit
REEFVTS	Vessel Traffic System in the Torres Strait and Great Barrier Reef Marine Park
UKC	Under Keel Clearance
VTS	Vessel Traffic System

Appendix B National Plan for Combat of Oil Pollution at Sea

B.1 Background

The National Plan was established in 1973 as a national integrated Government and Industry organisation framework enabling an effective response to marine pollution incidents. The plan provides a national framework for responding promptly to marine pollution incidents by maintaining:

- National Marine Oil and Chemical Spill Contingency Plans
- Detailed state and industry contingency plans
- Strategically placed response equipment
- National training programs (AMSA, October 2012).

B.2 History of oil spills in Australia

Table 2 **History of oil spills**

Date	Source of Spill	Location	Spill volume
28/06/1999	Mobile Refinery	Port Stanvac, SA	230 tonnes
26/07/1999	MV Torungen	Varanus Island, WA	25 tonnes
03/08/1999	Laura D'Amato	Sydney, NSW	250 tonnes
18/12/1999	Sylvan Arrow	Wilson's Promontory, VIC	<2 tonnes
02/09/2001	Pax Phoenix	Holbourne Island, QLD	<1 tonne
25/12/2002	Pacific Quest	Border Island, QLD	Volumetric estimate unavailable but >70 km slick reported
24/01/2006	Global Peace	Gladstone, QLD	25 tonnes
08/06/2007	Pasha Bulker	Newcastle, NSW	Nill spill volume. Significant bumkers and lubricant oil held onboard posing a threat during vessel salvage
11/03/2009	Pacific Adventurer	Moreton Island, QLD	270 tonnes
21/08/2009	Montara Wellhead	NW Australian coast	~4,750 tonnes
03/04/2010	Shen Neng 1	Near Great Keppel Island, QLD	4 tonnes

Source: (AMSA, October 2012)

B.3 Risk assessment

A risk assessment Commissioned by AMSA was carried out by DNV in 2011 taking into account safety measures, including:

- Requirements for doubled hull protection
- Traffic separation schemes
- Vessel Traffic Services
- Compulsory pilotage
- Emergency towage vessels.

The estimate also reviewed 2020 taking into account

- 79 per cent growth in national port traffic by 2020
- 81 per cent growth in national traffic by sea by 2020
- Offshore oil production would reduce by 89 per cent while condensate production would increase by 73 per cent (AMSA, October 2012)

The study did not take into account the impact of LNG shipping that is also expected to grow significantly in the coming 7 years.

Oil spill risk for 2011 and 2020 is summarised in the following tables.

Table 3 **Oil spill risk assessment 2011**

Source	ERI (million A$ per year)	%
Trading ships at sea	2.6	29.1%
Trading ships in port	4.5	49.7%
Small commercial vessels	0.1	1.2%
Offshore production	0.6	6.2%
Offshore drilling	0.2	2.3%
Shore based	1.1	11.5%
Total	9.1	100.0%

Source: (AMSA, October 2012)

Table 4 **Oil spill risk assessment 2020**

Source	ERI (million A$ per year)	% of 2020	% Increase from 2010
Trading ships at sea	5.0	28.3%	91%
Trading ships in port	10.9	60.9%	141%
Small commercial vessels	0.1	0.6%	7%
Offshore production	0.4	2.3%	-28%
Offshore drilling	0.2	1.2%	0%
Shore based	1.2	6.7%	14%
Total	17	100.0%	96%

Source: (AMSA, October 2012)

Appendix C Minimum maritime user requirements

Table of the minimum maritime user requirements for general navigation

	System level parameters				Service level parameters			
	Absolute Accuracy	Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval[2] (seconds)
	Horizontal (metres)	Alert limit (metres)	Time to alarm[2] (seconds)	Integrity risk (per 3 hours)				
Ocean	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Coastal	10	25	10	10^{-5}	99.8	N/A[1]	Global	1
Port approach and restricted waters	10	25	10	10^{-5}	99.8	99.97	Regional	1
Port	1	2.5	10	10^{-5}	99.8	99.97	Local	1
Inland waterways	10	25	10	10^{-5}	99.8	99.97	Regional	1

Notes: 1: Continuity is not relevant to ocean and coastal navigation.
2: More stringent requirements may be necessary for ships operating above 30 knots.

Tables showing the minimum maritime user requirements for positioning

	System level parameters					Service level parameters			
	Accuracy		Integrity			Availability **% per 30 days**	Continuity **% over 3 hours**	Coverage	Fix interval[2] (seconds)
	Horizontal (metres)	Vertical[1] (metres)	**Alert limit (metres)**	Time to alarm[2] **(seconds)**	Integrity risk **(per 3 hours)**				
Operations	Relative accuracy								
• tugs and pushers	1		2.5	10	**10^{-5}**	99.8	**99.97**	**Local**	**1**
• icebreakers	1		2.5	10	**10^{-5}**	99.8	**99.97**	**Local**	**1**
• automatic collision avoidance	10		25	10	**10^{-5}**	99.8	**99.97**	**Global**	**1**
	Absolute accuracy								
• track control	10	N/A	25	10	**10^{-5}**	99.8	**99.97**	**Global**	**1**
• automatic docking	0.1		0.25	10	**10^{-5}**	99.8	**99.97**	**Local**	**1**
Traffic management[3]	**Absolute accuracy**								
• ship-to-ship co-ordination	10		25	10	**10^{-5}**	99.8	**99.97**	**Global**	**1**
• ship-to-shore co-ordination	10		25	10	**10^{-5}**	99.8	**99.97**	**Regional**	**1**
• shore-to-ship traffic management	10		25	10	**10^{-5}**	99.8	**99.97**	**Regional**	**1**

Notes: 1: There may be a requirement for accuracy in the vertical plane for some port and restricted water operations.
2: More stringent requirements may be necessary for ships operating above 30 knots.
3: Traffic management applications in some areas, e.g. the Baltic, may require higher accuracy.

Table 1: Manoeuvring and traffic management applications.

	System level parameters					Service level parameters			
	Accuracy		Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval (seconds)
	Horizontal (metres)	Vertical (metres)	Alert limit (metres)	Time to alarm (seconds)	Integrity risk (per 3 hours)				
Search and rescue	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
Hydrography	1 - 2	0.1	2.5 - 5	10	10^{-5}	99.8	N/A	Regional	1
Oceanography	10	10	25	10	10^{-5}	99.8	N/A	Global	1
Marine engineering, construction, maintenance and management									
• dredging	0.1	0.1	0.25	10	10^{-5}	99.8	N/A	Local	1
• cable and pipeline laying	1	N/A	2.5	10	10^{-5}	99.8	N/A	Regional	1
• construction works	0.1	0.1	0.25	10	10^{-5}	99.8	N/A	Local	1
Aids to navigation management	1	N/A	2.5	10	10^{-5}	99.8	N/A	Regional	1

Table 2: Search and rescue, hydrography, oceanography, marine engineering, construction, maintenance and management and aids to navigation management

	System level parameters					Service level parameters			
	Accuracy		Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval[1] (seconds)
	Horizontal (metres)	Vertical (metres)	Alert limit (metres)	Time to alarm[1] (seconds)	Integrity risk (per 3 hours)				
Port operations	**Absolute accuracy**								
• local VTS	1	N/A	2.5	10	10^{-5}	99.8	N/A	Local	1
• container/cargo management	1	1	2.5	10	10^{-5}	99.8	N/A	Local	1
• law enforcement	1	1	2.5	10	10^{-5}	99.8	N/A	Local	1
• cargo handling	0.1	0.1	0.25	1	10^{-5}	99.8	N/A	Local	1
Casualty analysis	**Predictable accuracy**								
• ocean	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
• coastal	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
• port approach and restricted waters	1	N/A	2.5	10	10^{-5}	99.8	N/A	Regional	1
Offshore exploration and exploitation	**Absolute accuracy**								
• exploration	1	N/A	2.5	10	10^{-5}	99.8	N/A	Regional	1
• appraisal drilling	1	N/A	2.5	10	10^{-5}	99.8	N/A	Regional	1
• field development	1	N/A	2.5	10	10^{-5}	99.8	N/A	Regional	1
• support to production	1	N/A[2]	2.5	10	10^{-5}	99.8	N/A	Regional	1
• post-production	1	N/A[2]	2.5	10	10^{-5}	99.8	N/A	Regional	1

Notes: 1: More stringent requirements may be necessary for ships operating above 30 knots.
2: A vertical accuracy of a few cm (less than 10) is necessary to monitor platform subsidence.

Table 3: Port operations, casualty analysis, and offshore exploration and exploitation

	System level parameters					Service level parameters			
	Accuracy		Integrity			Availability % per 30 days	Continuity % over 3 hours	Coverage	Fix interval[1] (seconds)
	Horizontal (metres)	Vertical (metres)	Alert limit (metres)	Time to alarm[1] (seconds)	Integrity risk (per 3 hours)				
Fisheries	**Absolute accuracy**								
• location of fishing grounds	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
• positioning during fishing[2]	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
• yield analysis	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
• fisheries monitoring	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
Recreation and leisure	**Absolute Accuracy**								
• ocean	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
• coastal	10	N/A	25	10	10^{-5}	99.8	N/A	Global	1
• port approach and restricted waters	10	N/A	25	10	10^{-5}	99.8	99.97	Regional	1

Notes: 1: More stringent requirements may be necessary for ships operating above 30 knots.
2. Positioning during fishing in local areas may have more stringent requirements.

Table 4: Fisheries, recreation and leisure applications

Appendix D References

Access Economics. (2005). *The Economic and Financial Value of the Great Barrier Reef Marine Park*. Townsville: Great Barrier Reef Marine Park Authority.

AMSA. (2012). *2012 Annual Report*. Canberra: Australain Maritime Safety Authority.

AMSA. (2012). *Differential Global Positioning System DGPS Fact Sheet*. Canberra: Australian Maritime Safety Authority.

AMSA. (April 2010). *Improving safe navigation in the Great Barrier Reef*. Canberra: Australian Maritime Safety Authority.

AMSA. (July 2011). *REEFVTS User Guide*. Canberra: Australian Maritime Safety Authority.

AMSA. (March 2012). *Submission to the Department of Transport and Infrastructure on National Positioning Infrastructure*. Canberra: Australian Maritime Safety Authority.

AMSA. (October 2012). *Report on the 2011-12 review of the National Plan to Combat Oil Pollution of the Sea by Oil and other Hazardous Materials*. Canberra: Australian Maritime Safety Authority.

BITRE. (2012). *Australian Sea Freight 201-11*. Canberra: Australian Bureau of Infrastructure and Transport and Regional Economics.

HANSA. (2013). Charter rates. *International Maritime Journal*.

IMO. (2001). *Resolution A.915(22)*. London: International Maritime Organization.

IMO. (2009). *MSC 85/26/Add 1 Annex 20*. London: Internaitional Maritime Organization.

IMO. (July 2007). *Navigation Committee meeting 53*. London: IMO.

International Maritime Organization. (2001). *Revised maritime policy and reqwuirements for a future GNSS*. London: International Maritime Organisation.

Keysers, J. (2013). *Vertical Datum Trasnforation across the Australian Littoral Zone*. Melbourne: CRC Si.

Lemon, N. (2010). *e-navigation - a new paradigm*. Canberra: Australian Maritime Safety Authority.

Navicom Dynamics. (2013). *Harbour Pilot Portable Navigation Unit Brochure*. info@navicomdynamics.com.

PGM Environment. (2012). *Great Barrier Reef Shipping: Reveiw of Environmental Implications*. Safety Bay WA: PGM Environment.

Thomson Clarke. (March 2007). *Assistance with the Implementation of an under keel clearance system for Torres Strait*. Canberra: Australian Maritime Safety Authority.

ACIL ALLEN CONSULTING

Precise positioning services in the aviation sector

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

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

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Executive summary

GNSS is playing an increasing role in navigation in regional airlines and general aviation augmented by terrestrial navigation aids to provide a degree of redundancy in the navigation systems pilots rely on. Commercial aircraft generally operate with more comprehensive navigation instruments including Instrument Landing Systems (ILS), barometric systems (Baro-VNAV) as well as augmented GNSS.

Non precision approaches rely on GNSS for lateral guidance. All aviation certified GNSS receivers must have Receiver Autonomous Integrity Monitoring (RAIM) which is augmented with signals from static monitors to confirm the integrity of the GNSS for use by aircraft.

Navigation with RAIM enabled GNSS has delivered some benefits in terms of the ability for aircraft to fly user preferred routes which reduces fuel use and costs. In Australia it could allow the number of terrestrial navigation aids to be reduced. There is potential to reduce the number of terrestrial aides on regional routes after 2016 by not replacing them at the end of their operating life. The capital costs avoided would be around $119 million.

Further augmentation is possible from Ground Based Augmentation Systems (GBAS) and Space Based Augmentation Systems (GBAS). GBAS could theoretically replace existing ILS infrastructure at major airports for precision approaches. Precision approaches increase the safety and utilisation of airports in bad weather and thereby increase their operating capacity. They also reduce costs of lost time and fuel from diversions and delays caused by bad weather.

GBAS, along with other navigation systems that provide vertical guidance, reduce the fuel used in airport approaches. This is estimated to be of the order of $36 million per year if savings at all major airports are be included. GBAS also has cost advantages over Instrument Landing Systems (ILS) for precision approaches. The infrastructure it requires is less restrictive on runways and lower cost.

A GBAS has been installed at Sydney Airport and one is to be installed at Melbourne Airport in 2016. However the ILS systems will not be retired because not all commercial aircraft are GBAS equipped. The cost advantage of GBAS will not be realised until the ILS systems are retired.

SBAS is a wide area augmentation system where augmentation is delivered by satellite signal. Earlier economic studies and calculations undertaken by ACIL Allen show that it is unlikely that the net benefits to the aviation sector alone would exceed the cost of an SBAS.

There are currently no plans to develop an SBAS in Australia. Any consideration of this matter would need to be considered in the context of national positioning infrastructure and not in the context of the aviation sector alone.

Key findings

- Global Navigational Satellite Systems (GNSS) are increasingly being used in all sectors of the aviation industry as an aid to navigation. The regulatory authorities have acknowledged this trend and incorporated GNSS in regulatory policy and procedures.
- Aircraft navigation does not generally require high horizontal position accuracy.
  - The accuracy available from stand-alone GNSS is sufficient for most situations.
  - Integrity is more important with around 4 nautical miles over ocean, 2 nautical miles over land and 0. 3 nautical miles required for non-precision approaches.
  - Precision approaches require integrity of around 40 metres.
- Higher levels of vertical positional accuracy are however required for precision approaches and landings.
- There are two navigation technologies that provide precision approaches
  - instrument Landing Systems (ILS) that broadcast a flight path from radio beacons on the airstrip that are received by an ILS receiver in the cockpit
  - Ground Based Augmentation Systems that provide augmented GNSS at airports.
  - While GBAS would deliver savings in fuel costs if installed at all 9 major airports compared to approaches with vertical guidance, ILS delivers similar savings and is already installed.
  - GBAS would also deliver cost savings for infrastructure compared to ILS. However ILS is to be maintained for the time being as not all aircraft are GBAS equipped.
- Savings in capital costs to replace terrestrial navigation aids of around $119 spread are possible with RAIMS capable GNSS.
- Space Based Augmentation Systems (SBAS) provide augmented GNSS over a wide area, however, the net benefits of an SBAS to the aviation sector alone do not appear to be sufficient to justify the cost.

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. This report addresses the aviation sector.

The purpose of this report is to provide an understanding of the economic and social benefits of precise positioning information within the aviation 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 Aviation use of precise positioning

2.1 Background

The aviation sector is an international industry with demanding safety of navigation standards and procedures for a wide range of aviation operations. The International Civil Aviation Organisation (ICAO) provides the forum for setting standards and procedures. Member states of ICAO have determined that aeronautical navigation services for the 21st century will increasingly be based on global navigational satellite systems (GNSS).

The Aviation White Paper released in 2009 supported the wider application of satellite navigation technology along with the use of other satellite surveillance technologies, such as Automatic Dependent Surveillance-Broadcast (ADSB) and ground-based surveillance capability, including radar to protect against vulnerabilities from over-reliance on one system (DITRDLG, December 2009).

Commercial aircraft now rely on integrated Flight Management Systems (FMS) involving a range of technologies including GNSS, inertial position sensing, terrestrial navigation aids and barometric height measurement.

2.2 Aviation positioning requirements

Aviation operations depend on pilots and air traffic controllers for the save execution of take-offs and landings, flight en-route and for the management of aircraft on the ground. Pilots and air traffic controllers in turn rely on a range of aids-to-navigation to augment visual cues for safety of operation and navigation.

Aids-to-navigation range from paper maps and compasses to sophisticated electronic navigation systems. In the cockpit they include altimeters, radio receiver, instrument landing systems and radar to provide the pilot (and the auto pilot in certain circumstances) with horizontal and vertical position information. For air traffic control, they include radar, electronic charts and aircraft reporting systems. For air search and rescue they include satellite based distress beacons and electronic mapping and charting.

GNSS is playing an increasing role in navigation in regional airlines and general aviation augmented by terrestrial navigation aids to provide a degree of redundancy in the navigation systems pilots rely on. Commercial aircraft generally operate with more comprehensive navigation instruments including Instrument Landing Systems (ILS), barometric systems (Baro-VNAV) as well as stand-alone and augmented GNSS.

Over the past 10 years or so, aircraft navigation systems have been improved to provide pilots with more accurate location information and the position of other aircraft. Developments include Required Navigation Performance (RNP-AR) procedures[1], user preferred routings and Automatic Dependence Surveillance Broadcast (ADSB). These processes have improved the management of aircraft both en-route and for airport approaches and departures (for more details see Box 1).

GNSS has become an important aid to navigation for aircraft. However its use in aviation requires additional augmentation to meet aviation standards. All aviation certified GPS[2] receivers are required to have Receiver Autonomous Monitoring (RAIM) which is a form of GNSS augmentation.

Further augmentation is possible through Ground Based Augmentation Systems (GBAS) and Space Based Augmentation Signals (GBAS). GBAS has been installed at Sydney Airport and is scheduled to be installed at Melbourne airport in 2016.

Examples of government run SBAS systems overseas include the Wide Area Augmentation System (WAAS) operating in the United States and the EGNOS system in Europe.

[1] RNP AR refers to Required Navigation Performance Authorisation Required refers to a range of aircraft operational procedures including approach procedures but it can also apply to missed approaches, standard instrument procedures.

[2] GPS stands for the Navstar Global Positioning System operated by the United States and made available free for use in Australia.

Box 1 Examples of improved on-board navigation

Horizontal accuracy: RNP-AR

RNP-AR (Required Navigation Performance – Authorisation Required) was developed by ICAO as a set of procedures and performance requirements to facilitate change in airspace operation in recognition of changes in global satellite systems, navigational infrastructure, operations and aircraft systems. Receiver Autonomous Instrument Monitoring (RAIM) is form of GNSS based navigation that has supports RNP-AR provides accuracy to 0.1 miles or better. This technology has been developed from better on-board assessment of data from satellite constellations location information for example), lateral thinking about the design of airport approaches, and rethinking the monitoring of airport positions. While not high resolution, it has produced substantial operational benefits for airlines.

Use of RNP instead of the traditional instrument landing system (ILS) at Brisbane allowed the straight-line approach to the airport to be reduced from up to 17 miles to approximately 2 miles, implying a reduction of 4% if applied to both ends of a typical 500 mile (800km) flight such as Sydney-Brisbane or Sydney-Melbourne (there are also noise and emission benefits). Several years ago Airservices reported that it was found that 3200 flights saved 700 tonnes of fuel. RNP-AR technology also allows a smooth rather than stepped descent, saving power.

The approach also allows higher take-off weights at constrained airports, in turn allowing more passengers and freight, and/or more fuel. For example, in Queenstown, NZ, with mountainous terrain and variable weather, the technology allows the airport to be used for a greater number of days and, by facilitating a better climb-out route, allows direct flights to Australia which previously had to refuel in Christchurch. Although Australia does not have airports with such dramatic constraints, it has economic benefits at airports with relatively minor terrain challenges. RNP departure allows Canberra – Perth to be unconstrained; conventional departure is payload limited. RNP departure at Cairns and Hobart also allows higher weights (payload).

RNP-AR uses ABAS and GPS with RAIM for lateral guidance and Baro-VNAV for vertical guidance.

User-preferred routings

Information from the world wind model is input into aircraft navigation planning, so an airline can determine a route that minimises experience of headwinds and maximises use of tail winds. Use of RNP navigation and Controller-Pilot Data-Link allowed initial implementation across the Pacific Ocean followed by the Indian Ocean and more recently on distant domestic airport pairs – Perth-Cairns, Perth-Brisbane.

An Airservices study several years ago found an average of 13 minutes is saved on each 14 hour flight between Los Angeles and Sydney. Los Angeles-Melbourne flights only became economic once user-preferred routings had been introduced; previous use of sub-optimal routes meant that an intermediate stop (e.g. Sydney or Auckland) was needed or that payloads so restricted that the operation was uneconomic.

Automatic Dependent Surveillance Broadcast

Automatic Dependant Surveillance Broadcast (ADSB) is a system that gives aircraft the capacity to automatically broadcast aircraft position, altitude, velocity and other data continuously. Other aircraft and ATC can access the data on display screens without the need for radar. ADSB systems have been defined and standardised by ICAO and other standards organisations worldwide.

Aircraft position is derived from the GNSS or internal navigation systems on board the aircraft. The ground unit is simply a receiver for the data, which is then integrated into the Air Traffic Control (ATC) System. ADSB units are currently being deployed to provide surveillance of airspace above 30,000 feet over the entire continent, including areas not currently provided with radar coverage. 30 ADS-B ground stations are in use across Australia with coverage above 29,000ft. 95% of international flights and 86% of domestic flights above 29,000ft are ADSB equipped and receive surveillance based services[3].

Source: Sydney Airport Master Plan 2009; Airservices; ACIL Allen.

[3] http://www.airservicesaustralia.com/projects/ads-b/upper-airspace-mandate-2013/

2.2.1 Horizontal accuracy

Integrity is a critical performance criterion for GNSS used by aircraft. Integrity is the limit of error for which an aircraft will be warned that the GNSS position information is not correct. Aircraft do not generally require high position integrity in the horizontal plane. In broad terms integrity of around 4 nautical miles is sufficient when flying over ocean and 2 nautical miles is sufficient for flying over land. Non-precision airport approaches, where pilots align their planes for landing visually, require integrities of around 0.3 nautical miles horizontal accuracy. Lateral guidance for precision approaches is more demanding but varies depending on the terrain. In general precision approaches require integrity of around 40 metres.

2.2.2 Vertical accuracy

While high horizontal accuracy is less important, aviation requires higher vertical accuracy. The level of accuracy required depends on the landing decision height or how close to the ground the vertical guidance system is used.

Non precision approaches

Non-precision approaches rely on visual guidance by the pilot for which the minimum required height for visual identification of an airstrip (decision height) is around 500 feet to 600 feet depending on terrain. The altimeter is sufficient for navigation at this height. An altimeter has a vertical accuracy of around 75 feet. Non-precision approaches are not considered adequate for high density regular public transport (RPT). CASA reports a significant number of near misses in RPT aircraft (Mallet, 6 December 2012).

Approach with vertical guidance (APV) is the highest capability in non-precision approach systems. APV can support multiple glide paths and touchdown zones, does not require runway specific infrastructure and is not subject to path aberration or periodic flight calibration (Scott, 2012).

APV uses RIAM augmented GNSS for horizontal position and altimeter readings and (Baro-VNAV) for vertical position.

Precision approaches

Precision approaches (CAT-I[4]) require minimum decision height of around 200 feet. Guidance can be provided by an Instrument Landing System (ILS) or by GBAS.

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[4] There are three Categories of instrument landing systems for aircraft. Category 1 (CAT 1) applies to landing decision heights of 200 feet, CAT 2 applies for decision heights of 100 feet and CAT 3 allows decision heights ranging between 0 and 100 feet. Australian airports operate on CAT 1.

Precision approaches are superior to APV because they provide guidance to a lower decision height.

2.3 Navigation technologies

2.3.1 RAIM

RAIM uses inertial systems in GNSS receivers to validate signals from GNSS satellites. However, inertia is insufficient to evaluate GNSS performance on its own. For air navigation RAIM is augmented through the use of static monitors at known (surveyed) locations which transmit integrity data to the receiver. The combination of the use of RAIM and monitoring from ground stations is a form of augmentation to the GNSS signal.

RAIM monitoring for aircraft reduces the need for terrestrial navigation aids which in the long run will reduce costs of replacing and maintaining them. Terrestrial navigation aids are supported by Airservices Australia. With the use of signal monitoring GNSS and RAM it will be possible to reduce the terrestrial navigation aid for en route flying. Airservices Australia advised that this not likely to occur until after 2016 when some of the existing aids need to be replaced. The cost of replacement of all the terrestrial aids is estimated to be around $119 million.

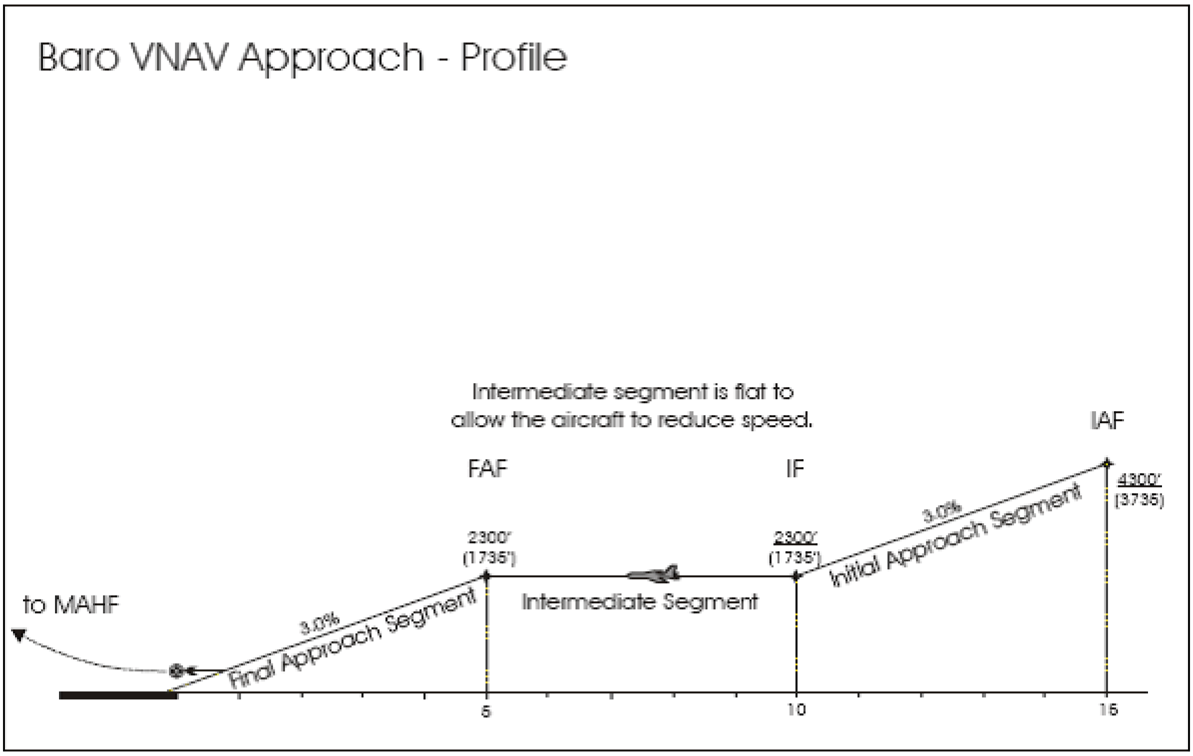
GNSS/RAIM also permits user preferred routes to be flown by international and regional airlines. This reduced the travel distance and travel time and saves fuel and emissions of $CO_{2.}$

2.3.2 Baro VNAV

APV Baro-VNAV utilises GNSS for lateral navigation and barometrically derived data for vertical navigation. APV Baro-VNAV procedures are intended for use by aircraft equipped with a flight management system or other area navigation systems capable of constantly computing barometric paths and displaying the relevant deviations on the instrument display.

The minimum vertical accuracy required under APV is 75 feet. This allows the minimum height for visual identification of the airstrip to be reduced from 166 metres to 260 feet. For this level of accuracy barometric measurement is sufficient. A typical approach path under Baro-VNAV is shown in Figure 1.

Figure 1 **Baro VNAV approach profile**



Data source: (ATNS, 2012)

While Baro VNAV provides a significant improvement in safety (8 times safer than visual straight in approaches according to CASA[5]) it also requires a straight in approach which limits flexibility of air traffic management at busy airports. It is also important to note that most general aviation aircraft do not have Baro-VNAV instrument capability.

2.3.3 Instrument Landing Systems (ILS)

ILS broadcasts a flight path from radio beacons on the airstrip that are received by an ILS receiver in the cockpit. The system provides the pilot with instrument indications which, when utilised in conjunction with the normal flight instruments, enables the aircraft to be manoeuvred along a precise, predetermined, final approach path[6].

Currently 16 major Australian airports have ILS capability. ILS is an economic option at major airports, given large traffic volumes. An ILS installation costs around $1.5 million per unit and maintenance and flight checks costing about $120,000 per annum[7]. There are also aircraft equipment and maintenance costs associated with ILS.

[5] (Mallet, 6 December 2012)

[6] CASA website

[7] CASA Discussion Paper DP 1006AS

An ILS approach must be a straight runway aligned 3 degree descent path that cannot be varied from aircraft to aircraft. This can be an issue for busy metropolitan airports where greater flexibility in flight paths is an increasing imperative.

2.3.4 GBAS

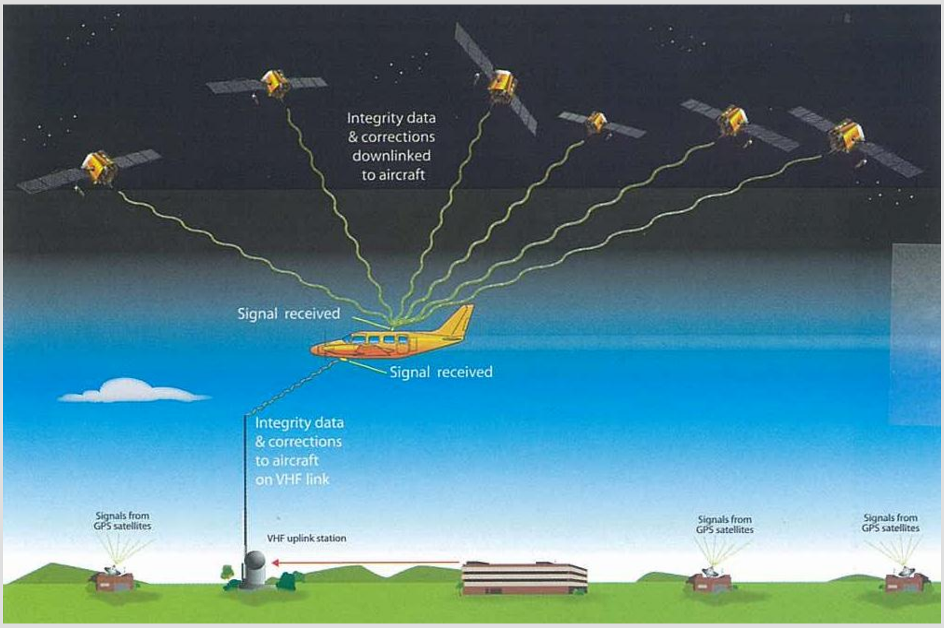
GBAS is a system that uses ground based reference stations at Airports to provide augmentation signals to the GNSS receiver on the flight deck. Its working arrangements are outlined in Box 2. GBAS is designed from an aircraft perspective to look like a traditional instrument landing system (ILS). It is used in conjunction with other instruments to report vertical position during the descent.

GBAS can provide vertical accuracy of 1 metre and transmit this 5 times per second with a probability of not detecting a corrupt GNSS signal of less than 2 in 10,000,000 (Williams, 6 December 2012). This is far higher than the accuracy that Baro-VNAV.

Airservices Australia has deployed a GBAS at Sydney Airport and has plans to install a GBAS system at Melbourne Airport in 2013. The nine other larger airports are expected to also have GBAS landing systems installed in subsequent years.

Box 2 **GBAS**

GBAS is a satellite-based precision approach and landing system that is established at an airport. A ground station at an airport transmits locally-relevant corrections, integrity and approach data to aircraft in the terminal area via VHF radio. GBAS is recognised by ICAO as a replacement for current ILS. It is a component of Australia's next-generation air traffic management infrastructure, particularly in the vicinity of capital city airports and will help reduce fuel burn, aircraft noise and airport delays.



Source: Sydney Airport Master Plan 2009; Airservices, CASA

Besides providing vertical accuracy, the system allows greater effective airport capacity than the traditional instrument landing systems (ILS), for example reducing waiting times before take-off after another flight has landed, and less reduction of capacity in bad weather (Scott, 2012).

GBAS supports multiple flight paths to the runway. The descent angle and touchdown point can be varied. While curved paths are possible they are not likely to be supported under the current arrangements.

Safety is increased through increased signal stability and system design. GBAS supports multiple straight in paths to the runway. The decent angle and touch down points can be varied. Curved paths are possible although not supported at Australian airports at the present time.

By comparison, ILS provides a beam to follow, which can mean one aircraft shades another, in turn requiring greater separation (e.g. waiting longer for take-off). The integrity, availability and continuity are an improvement on existing technology.

According to published papers[8] the benefits of GBAS are:

- For airlines it delivers:
  - improved safety
  - lower fuel costs
  - less flight disruptions and associated cost caused by ILS interference
  - minimal pilot training.
- Airports benefit from:
  - improved airport capacity from accurately guided, simultaneous operations to parallel runways and reduced runway exit times
  - flexibility in GBAS station location, unlock valuable airport land and alleviate traffic restrictions which are otherwise required to protect ILS signals from interference sources
  - improved airport access, especially where ILS cannot be installed for terrain or economic reasons.
- Air navigation service providers can obtain:
  - reduced traffic delays and congestion as a result of more efficient and predictable approaches
  - reduced capital investment cost and lower ongoing maintenance, as one GBAS covers all runways at an airport compared to one ILS installation required per one runway end
  - easier and less frequent flight inspections than ILS
  - continued operations even during routine flight inspection or airport works

[8] Information provided at Workshop on GBAS held on 13 December 2013 in Sydney (Scott, 2012), (Williams, 6 December 2012).

- greater ability to manage noise levels in built up areas through use of runway aligned straight in multiple flight paths.

There would also be economic benefits in improved safety at airports from more effective management of aircraft separation, benefits to airport operations through the ability to reduce wake induced separation and increase traffic volume and benefits to air traffic management at major airports in terms of greater flexibility in managing aircraft movements.

Both GBAS and ILS deliver similar benefit to aircraft. The principle difference is the greater freedom on touchdown on the runway that GBAS offers. An important benefit of GBAS compared to ILS systems relates to the fact that a GBAS would provide coverage for all runways at an airport while each ILS installation is runway specific. GBAS would have lower operating and capital costs than ILS.

2.3.5 SBAS

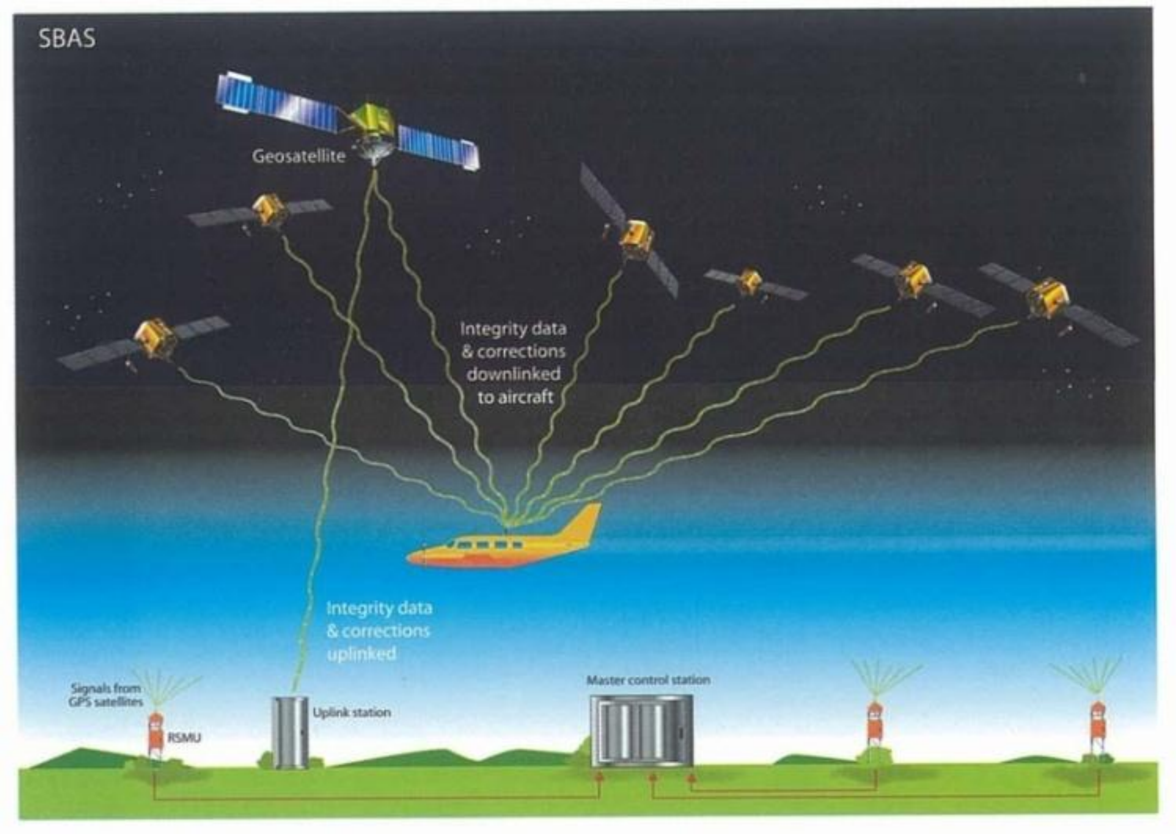
Space Based Augmentation System (SBAS) monitors the GPS satellites and broadcasts corrections and integrity information by satellite to aircraft (see Box 3). SBAS exists in the European Union, North America and Japan. China and India are well advanced in deploying a SBAS. These services are provided free of direct user charge. There are no SBAS services operating in Australia.

SBAS in Australia could be provided by a series of around 35 monitoring stations. The monitoring stations would have precise locations, map the ionosphere and broadcast corrections to aircraft via satellites. Their information would apply to all of Australia.

SBAS would enable augmentation services to be used on regional routes and by general aviation. A recent study by the Federal Aviation Authority in the United States suggested that one carrier had reduced regional cut as much as 25 per cent off its flight times for certain city-pairs by equipping GPS units with the wide area augmentation system (WAAS) in its Cessna fleet. Reduced flying times improved navigation at regional airports would be possible with an SBAS (Croft, 2013). However as discussed in section 3.3 the benefits to the airline sector alone are unlikely to exceed the costs.

Box 3 **SBAS**

SBAS delivers error corrections, extra ranging signals (from the geostationary satellite) and integrity information for each GNSS satellite being monitored. Like GBAS it also augments GNSS signals to provide aircraft with very precise positioning guidance, both horizontal and vertical. SBAS differs from GBAS in that it provides GPS integrity monitoring via satellites rather than VHF data link, rather than from the ground and potentially provides coverage for a wider geographical area.



Source: (DITRDLG, 2011)

Investment in an Australian SBAS carries with it a funding issue. Estimates of the cost of an SBAS for Australia range between $300 million and $1 billion (SBAS review, (CRCSI, 2011)).

While it is most likely that part of the cost of running SBAS would be recovered from the airline industry through landing and other charges, other users could free ride if the signal were not encrypted. Many other users in other industry sectors would benefit from an SBAS.

The Department of Infrastructure, Tourism, Regional Development and Local Government reviewed the advantages and disadvantages of an SBAS in 2011 (DITRDLG. (2011) and the CRC for Spatial Information undertook an economic assessment of an SBAS in 2011 in the context of a possible positioning component on the NBN satellite (CRCSI, 2011). The latter did not eventuate. At the present time there are no plans to develop an SBAS for Aviation in Australia although as discussed below, future developments in GNSS systems and technologies could make SBAS more feasible.

3 Economic and social impacts

3.1 Likely applications of augmentations to GNSS in the Australian Aviation Sector

The Aviation White Paper recognises the growing role of GNSS as an aid to navigation for the Australian aviation sector. This applies to the sophisticated integrated flight management systems of commercial aircraft and to the navigation systems used in general aviation.

The application of augmented GNSS systems in the foreseeable future is however most likely to be confined to its use in RAIM and GBAS systems. RAIM is already a requirement for GNSS receivers in aviation. GBAS systems are scheduled to be installed in major airports over the next decade or so.

With RAIM confirmation signals now in place, Airservices Australia will be able to retire en route terrestrial navigation aids from around 2016 realising total capital savings of around $119 million[9].

Not all aircraft will be fitted with GBAS capabilities and for the time being it will be necessary for major airports to retain their ILS infrastructure. While GBAS equipped aircraft will benefit from slightly more flexibility in approaches and landings, airports will not be able to realise the benefits of lower costs until they are able to retire their ILS infrastructure. There will be some benefits to airports in greater flexibility of aircraft management for those aircraft that can use GBAS enabled approaches the full benefits of greater flexibility are not likely to be fully realised until the majority of aircraft are GBAS capable.

There are no immediate plans to implement an Australian SBAS. While launches of new GNSS satellites such as the European Galileo or the Chinese Compass constellations may provide SBAS capability, their use in aviation is unlikely to be adopted in the short term. If they were, it may require local augmentation to address localised interference.

An SBAS would benefit regional airlines. However the major benefits of such systems are likely to be realised by other sectors such as agriculture, construction, transport and mining.

The economic and social impacts of precise positioning over the coming decade are therefore likely to be related to ongoing RAIM confirmation signals and installation of GBAS systems at major airports and their adoption by the commercial airlines. Adoption is likely to be gradual. While some aircraft are equipped with GBAS capability it may take time for it to be taken up. Some older aircraft will not adopt it.

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[9] Personal communication with Airservices Australia.

3.2 Economic impacts

3.2.1 2012

RNP-AR, user preferred routes and ABAS (described Box 1) have already delivered improvements and savings in aircraft operations, air traffic management and air safety. Baro-VNAV has already been rolled out at some airports to improve vertical guidance. The main augmentation system to stand-alone GNSS is the combination of RAIM and static monitoring of the GNSS signal.

RAIM monitoring is a part of the navigation support systems for RNP-AR. The latter has delivered benefits in reduced fuel costs for landing (see Box 4). The potential savings are of the order of $30 million per year.

Box 4 **Economic benefits from RNP-AR**

For the purpose of estimating the direct economic impacts of RAIM the savings in fuel for landings in 2020 for domestic commercial aircraft were estimated. The airline sector estimated that between 130 Kg and 200 Kg of fuel would be saved using landings based on RNP. In addition to these savings there would be reduced emissions of between 420 to 650 kg CO^2 per landing[10]. It was assumed that half of these savings could be attributed to the added accuracy of GBAS over Baro VNAV landings.

ACIL Allen estimated that this resulted in savings in fuel of around $30 million per year assuming RNP-AR approaches are used by all airlines at Australia's 9 major airports.

Source: ACILAllen based on data supplied by Qantas.

However while this is RAIM/ground monitored GNSS is a form of augmentation, ILS which is installed at these airports also delivers approximately the same benefits overall as far as fuel consumption is concerned[11]. Therefore no net benefit can be attributed to this technology for this report.

RAIM GNSS has delivered some benefits in enabling aircraft to fly user preferred routes domestically and internationally.

3.2.2 2020

While there are identifiable and quantifiable benefits that can be attributed to the installation of GBAS at Sydney and Melbourne Airports, and potentially other major airports, the fuel savings that could be attributed to more efficient approaches can also be delivered in general by ILS approaches and RNP – AR approaches. Therefore there is no net benefit that can be attributed to GBAS in terms of fuel efficiency on landings over alternative technologies at major airports.

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[10] Advice from Qantas.

[11] The differences in fuel consumption between RNP –AR and ILS approaches would vary between terrain and airport.

There are benefits in greater flexibility at airports potential benefits from the fact that GBAS covers all runways at an airport whereas ILS installations are runway specific. However for the time being both Sydney and Melbourne airports will continue to operate ILS systems as not all aircraft are fitted with GBAS capability at the present time. This situation is likely to apply in 2020.

Therefore no additional benefits have been attributed to the installation of GBAS at airports or the cost of infrastructure savings at this time.

It is likely however that with the requirement for the operation of RIAM GNSS in conjunction with static monitoring will enable the retirement of terrestrial navigation aids. This is likely to commence around 2016 saving capital expenditure of around $119 million spread over ten years. There would be some benefits that would also accrue from savings in aircraft flying user preferred routes.

3.3 Implications of SBAS

As discussed in this report earlier, there are currently no plans to develop an SBAS in Australia. Earlier economic studies and calculations undertaken by ACIL Allen show that it is unlikely that the net benefits to the aviation sector in fuel savings and improved navigation in regional areas would exceed the cost of an SBAS. For example ACIL Allen estimated the savings to regional and major airlines could be in the order of $10 million per year in fuel savings compared to capital costs estimates that have ranged between around $300 million to as high as $1 billion.

As the other reports in this series show, other sectors would also benefit from the development of an Australian SBAS. The overall net benefits may well exceed the costs of such an investment. Such developments however would need to be considered in the context of the National Positioning Infrastructure policy and not in the context of the aviation sector alone.

Appendix A Glossary of terms

Term	Meaning
GNSS	Global Navigational Satellite System
GPS	Global Positioning System – originally the term for the US Navstar GNSS
SBAS	Satellite Based Augmentation System
ABAS	Aircraft Based Augmentation System
GBAS	Ground Based Augmentation System
ADSB	Automatic Dependent Surveillance Broadcast
RNP AR	Required Navigation Performance Authorisation Required
AAIM	Aircraft Autonomous Integrity Monitoring
RAIM	Receiver Autonomous Integrity Monitoring
QZSS	The Japanese GNSS constellation of navigational positioning satellites.
Baro VNAV	Barometric height measurement – a component of APV
APV	Approach with vertical guidance

Appendix B References

Airbus. (2012). *Automatic Dependent Surveillance Broadcast (ADS B)*. Airbus Upgrade Services.

Airservices Australia. (2012). *Annual Report 2012*. Canberra: Airservices Australia.

ATNS. (2012). *Baro VNAV*. Republic of South Africa: ATNS Training Academy.

BITRE. (2012). *Air passenger movements through capital and non-captial city airports to 2030-31*. Canberra: Bureau of Infrastructure, Transport and Regional Economics.

CRCSI. (2011). *A space based augmnetation system for Australia*. Melbourne: Cooperative Research Centre for Spatial Information.

Croft, J. (2013, June 7). Cape air flight times down. *Aviation Week*, p. 5.

Delloitte Access . (2012). *Connection Australia - the economic and social benefit of Australian Airports*. Australian Airports Association.

Department of Climate Change and Energy Efficiency. (2013). *Forecast of emmissions from the Transport Sector*. Canberra: Department of Climate Change and Energy Efficiency.

Department of Climate Change and Energy Efficiency. (2013). *Projctions of emissions in the Transport Sector*. Department of Climatge .

DITR. (2008). *Aviation Green Paper*. Canberra: Department of Infrastructure, Transport and Regional Development.

DITRDLG. (2011). *SBAS review*. Canberra: Department of Infrastructure, Transport, Regional Development and Local Government.

DITRDLG. (December 2009). *National Aviation Policy White Paper*. December 2009: Department of Infrastructure, Transport, Regional Development and Local Government.

ICAO. (2009). *Required Navigation Performanc Authorisation Requiired (RNP AR) Procedure Design Manual*. Montreal: International Civil Aviation Authority.

Lateral Economics. (January 2009). *Nation Building for the Information Age*. Canberra: Lateral Economics.

Mallet, I. (6 December 2012). GLS Regulation and implementation. *GBAS Workshop*. Sydney: Civil Aviation Safety Authority.

Scott, R. (2012). Ground Based Augmentation System. *GBAS workshop*. Sydney: Airservices Australia.

Williams, E. (6 December 2012). Ground Based Augmentation Systems. *GBAS Workshop*. Sydney: Air Services Australia.