ACIL ALLEN
CONSULTING

The value of augmented GNSS in Australia

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

For information on this report

Please contact:

Alan Smart
Telephone   (02) 8272 5114
Mobile   0404 822 312
Email

a.smart@aciltallen.com.au

Contributing team members

David Greig - ACIL Allen   Paul Digney SKM
Chris Summerfield   Sam Griffiths - SKM
Michael Giudici - Lester   Seyed Miri - SKM
Franks

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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).

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[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

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[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[TM] 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

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[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

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[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 (Harcompe, 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.

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[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

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[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**
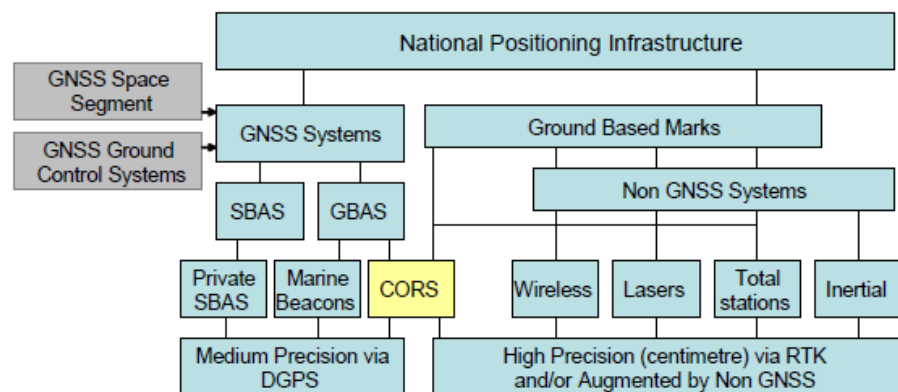
Data source: (ANZLIC, 2012)

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

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[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.

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[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.

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[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

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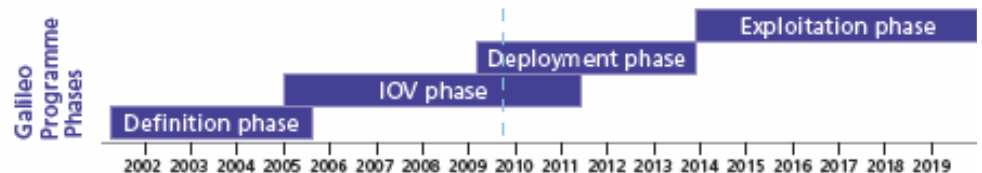
Data source: (UN Office for Outer Space Affairs, 2010)

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**
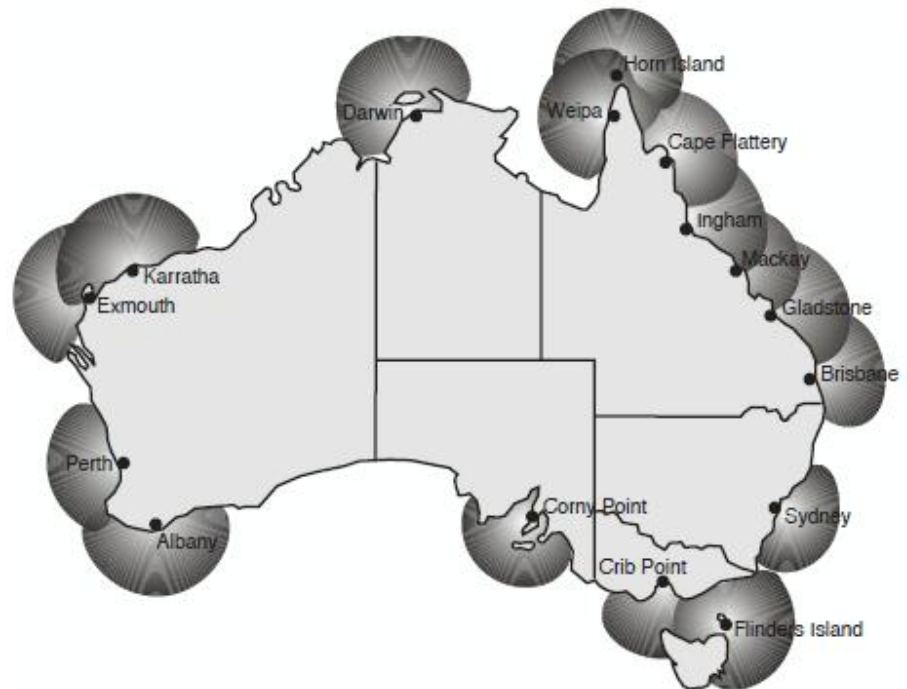
Source: AMSA.

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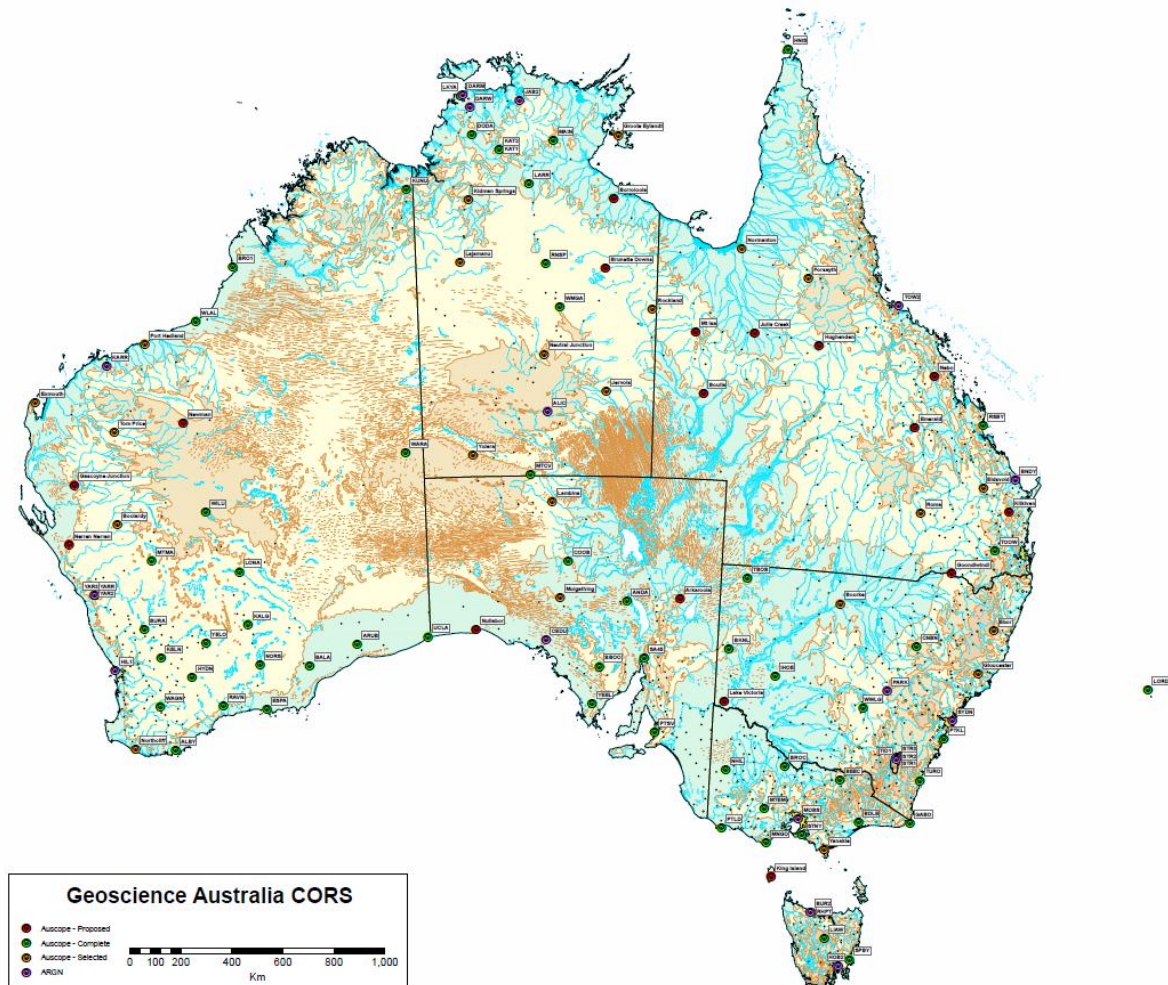
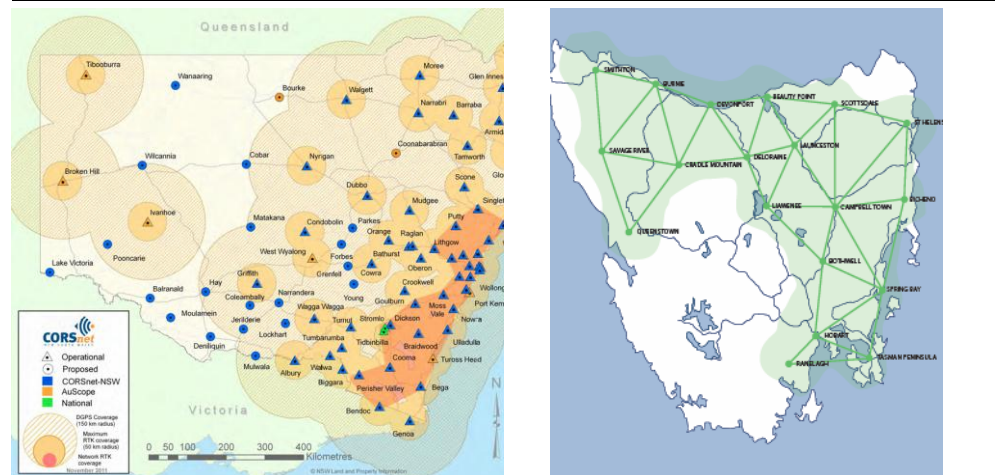*Data source:* if outside data used and we have charted it

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**
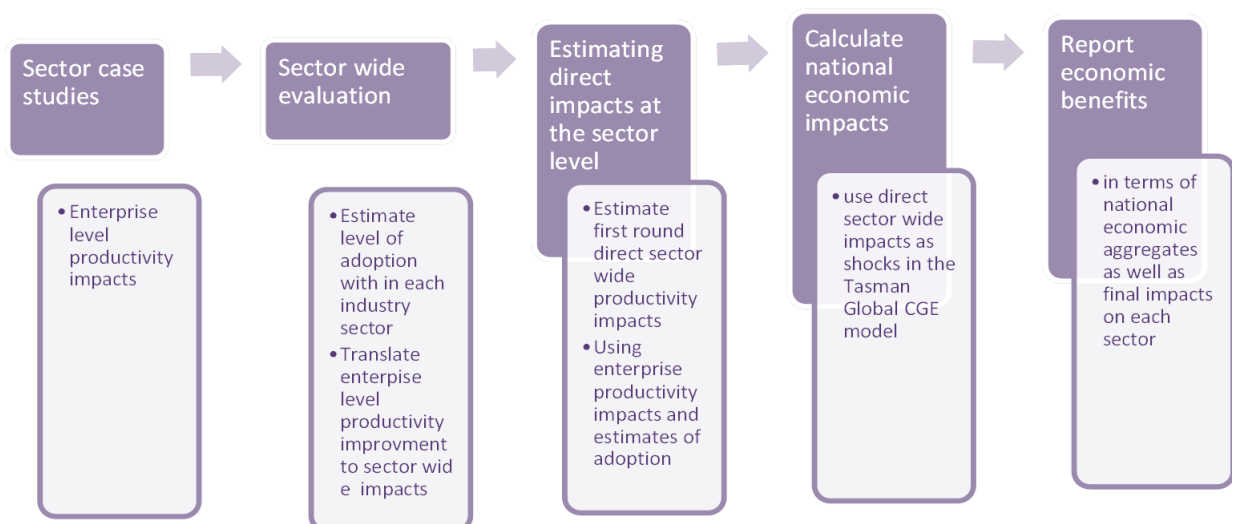
Source: ACIL Allen

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**
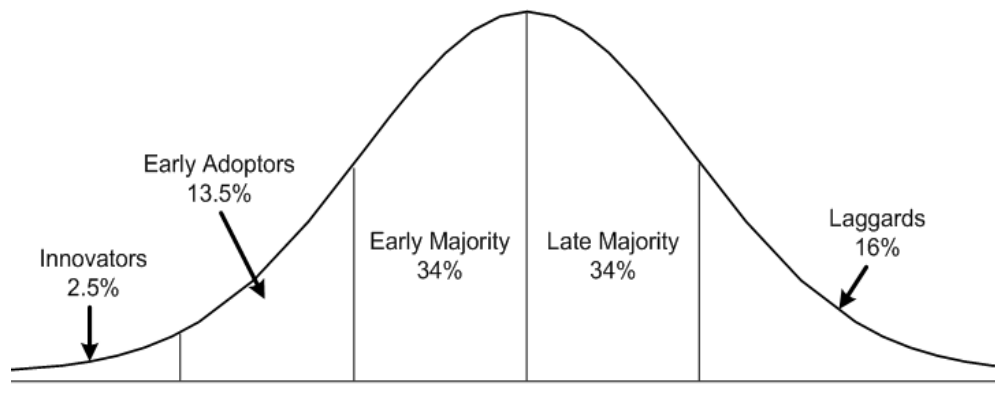
Data source: Rogers (1964)

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**
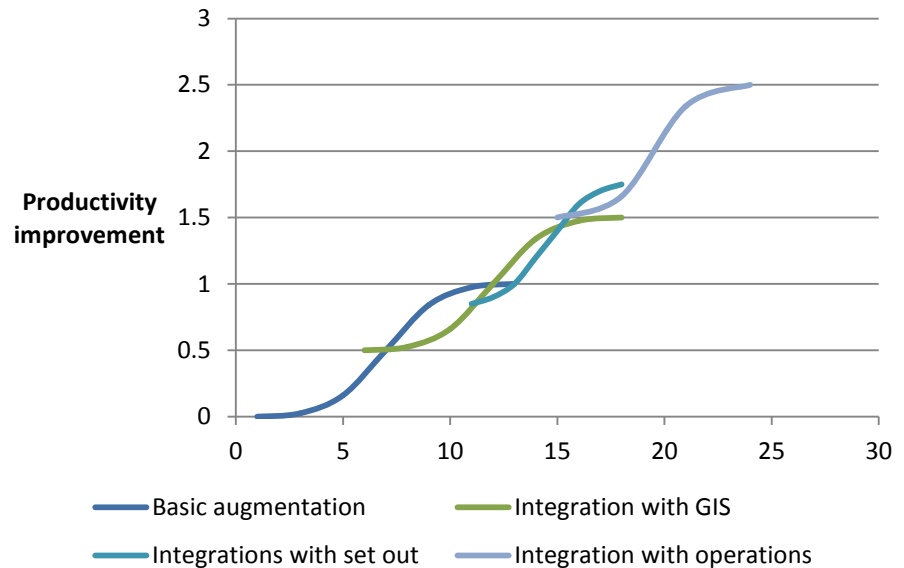
Note: levels of productivity are for illustrative purposes only.
Data source: (ConsultingWhere and ACIL Tasman, 2010)

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**
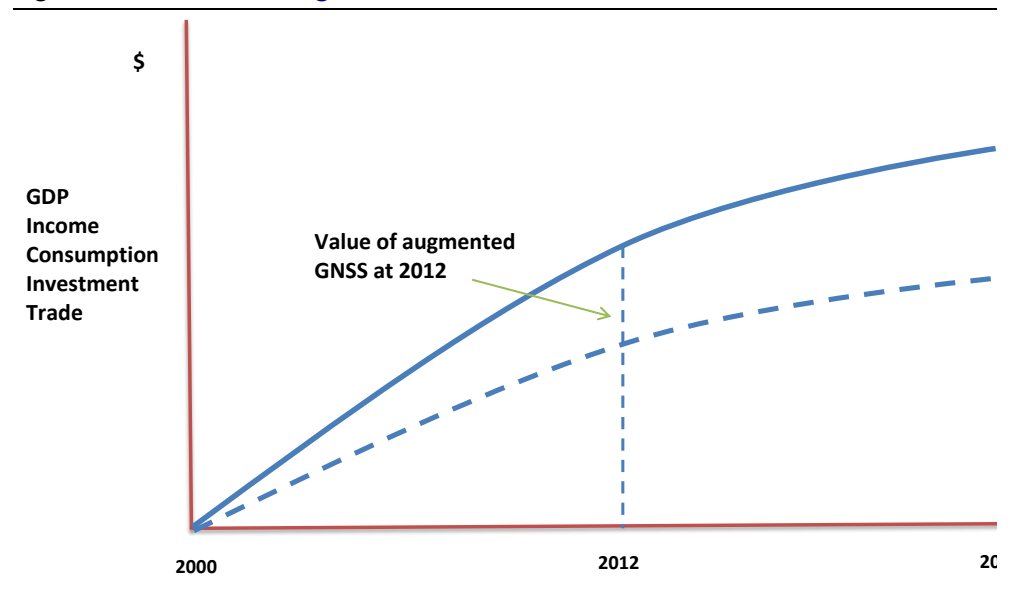
Data source: ACIL Allen

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[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

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[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**
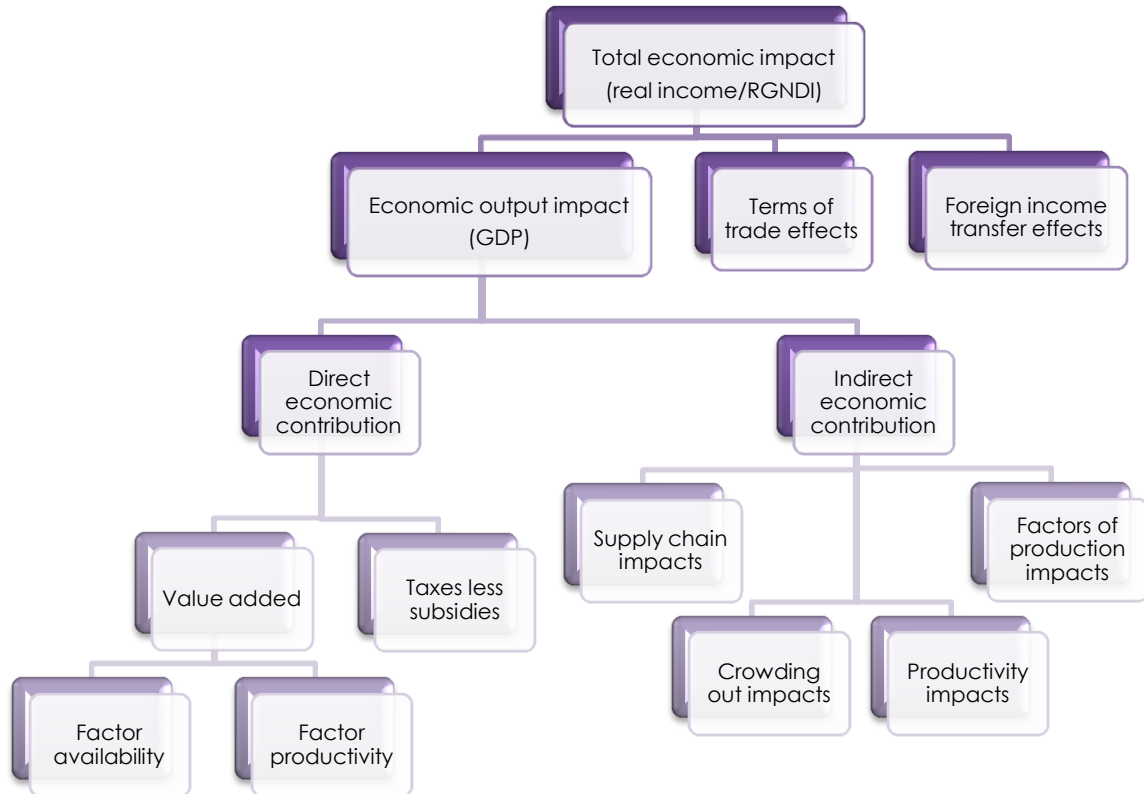
For many impact analyses, static estimates of the direct economic contribution and supply chain implications can be obtained through the use of I-O multipliers. Estimating the size of other components using multiplier techniques is either not possible or very complex, as is estimating the economic impacts 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 *PowerMark* 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

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