Position, Navigation and Timing

Working Group Report

March 2011

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Executive Summary

Positioning Navigation and Timing (PNT) infrastructure is an essential element of Australia's national public infrastructure.

The Global Positioning System (GPS), representing the first generation of a global space-based Positioning, Navigation and Timing utility (PNT1.0), has become a critical component of our transport, energy and communications infrastructures and has established itself as a key smart technology for increasing the productivity of our ports, mines, farms and construction sites.

Over the last decade, the terrestrial PNT infrastructure, which has evolved to support GPS users in Australia, has grown in an ad-hoc and uncoordinated manner. Only a few policy initiatives cover the area of spectrum licensing and protection. The result is that individual Commonwealth, state and private sector entities have established a patchwork of PNT1.0 infrastructure across Australia of varying capability, often duplicated and with no standards.

The full operational capability of the Russian GLONASS system, expected by the end of 2010, marks the dawn of the second generation of PNT (PNT2.0). By the end of this decade, it is expected that GLONASS will replace GPS with an interoperable "system of systems" from the US, Russia, EU, China, India and Japan.

With appropriate sovereign PNT infrastructure in place, PNT2.0 could bring substantial benefits to Australia. This includes an increase of at least $6.6 billion in GDP by 2030, safer airspace, more efficient transport networks, significant community benefits, and enhanced capabilities for measuring the impact of climate change.

Australia has been a leader in utilising PNT1.0 notably in the aviation, transport, agriculture, mining and geospatial industries. However, without coordination and investment by government in the infrastructure to support PNT2.0, we will inevitably fall behind other G20 nations in the effective and efficient utilisation of this critical space-based utility.

We therefore recommend that the Commonwealth government:

- Establish a permanent unit within government with responsibility for coordinating space related policy including Positioning Navigation and Timing infrastructure; and
- Invest between $500-600 million in coordinated, national PNT infrastructure comprising a Continuously Operating Reference Station (CORS) network and Satellite Based Augmentation System (SBAS) designed to be fully compatible with PNT2.0.

These investments should be made as early as possible to provide timely, secure and sustainable access to PNT2.0 and ensure Australia's society and industry benefit from the considerable economic, societal and environmental benefits that this important 21st century global utility will deliver.

Introduction

The dual-use Global Positioning System (GPS), fully operational since 1995, is the foundation for the first generation of a Positioning, Navigation and Timing utility (PNT 1.0) which operates within and throughout Australia's land, air and maritime boundaries.

GPS does more than help our citizens navigate. It synchronises communications and energy networks, reduces the costs of extracting and growing commodities, makes transport networks safer and more efficient, and helps protect borders and security.

As with all utilities, most Australians are only marginally aware of the technical complexities of delivering PNT services and the level of public and private sector investment in the research, skills, capabilities and infrastructure that underpin them.

With GPS, this lack of understanding is compounded. For consumers, the service is free and generally performs well. In circumstances when signals from space are not available (for example, in a high rise urban environment), it is seen as an inconvenience, and the technical challenges are rarely considered.

However, this belies the reality that for a steadily increasing portion of the Australian economy (including transport, agriculture and mining), the PNT service delivered by GPS and other navigation satellite systems is already an essential utility and for some sectors such as civil aviation it is a critical utility.

Further, many of those using PNT in the workplace or for safety-critical applications require not only uninterrupted signals from space, but also additional augmentation services from both publicly and privately owned terrestrial PNT infrastructure located in Australia.

This is an opportune time to conduct an analysis of PNT in Australia and a critical review of policy settings as the second generation of this utility (PNT2.0) is already being developed and launched.

PNT1.0 has been dominated by GPS. During this decade, PNT2.0 will emerge as a "system of systems". It will include an upgraded GPS along with Global Navigation Satellite Systems (GNSS) and Regional Navigation Satellite Systems (RNSS) from Russia, Europe, China, India and Japan.

The impact of all this investment in navigation satellites is that by 2020, PNT services and applications will be more ubiquitous. Our dependence on them will be even greater. This evolution is already underway with the Russian GLONASS set to become the second fully operational GNSS by the end of 2010. Thousands of combined GPS/GLONASS receivers are already in use on Australian mines, farms and construction sites.

PNT1.0 required little Australian Government involvement. However, the evolution to PNT2.0 will require an investment in both upstream and downstream capability by the middle of this decade to ensure full and secure access to the next generation of this important global utility.

Satellite Based Augmentation System

The US, Russia, EU, China, Japan and India are engaged on Global or Regional Navigation Satellite Systems (GNSS & RNSS) projects. This means there will be a continuous growth in the number of navigation satellites, from around 50 today to more than 120 by 2020. It also means there will be an increase in the range of signals that can be tracked, significantly increasing the availability and accuracy of GNSS.

However, even with these extra satellites and signals, for a substantial number of Australian GNSS & RNSS users the availability, accuracy or integrity of the raw navigation signals from space will not meet their requirements. Several significant industry sectors require additional augmentation services from a mix of space- and earth-based systems to cover our land, air and maritime domains.

From space, a Satellite Based Augmentation System (SBAS) would enable us to meet our international obligations for Performance Based Navigation (PBN) outlined in the Aviation White Paper[1]. This could be achieved for an estimated $190-300 Million[2] depending on the options selected. One of those options includes adding a payload to an Australian owned and operated communications satellite and supplementing existing ground control facilities in Australia. SBAS in North America and Europe are already in place and used by aviation, marine, agriculture, road, rail and other sectors. In the case of Europe, the economic impact of their SBAS is predicted to be €6 billion by 2030[3] for agriculture alone. Whether this impact would be similar for Australian agriculture would require further study.

Continuously Operating Reference Station

On the ground, a Continuously Operating Reference Station (CORS) network would assist in the delivery of important national gateway, freight rail, freight road and public transport infrastructure projects. A CORS network would also boost the net present value of GDP in the construction, mining and agriculture sectors by between $6.6 and $12.6 billion by 2030[4]. For an investment of $300[5] million[6], the impact of a national CORS is comparable to the economic gains projected for the adoption of equivalent smart systems in energy, e-Health, irrigation and transport outlined in the recent Access Economics report on the economic benefits of intelligent technologies.

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[1] National Aviation Policy White Paper, Department of Infrastructure and Transport, December 2009

[2] Positioning Australia for Growth: Strategic Investment in Ground-Based Infrastructure to Leverage Global Navigation Satellite Systems (internal document).

[3] http://www.gsa.europa.eu/go/news/extolling-the-virtues-of-high-precision

[4] The economic benefits of high resolution positioning services. Allan Consulting, 2008.

[5] Australian Spatial Consortium submission to Infrastructure Australia, November 2009

[6] Positioning Australia for Growth: Strategic Investment in Ground-Based Infrastructure to Leverage Global Navigation Satellite Systems (internal document).

SBAS principally provides signal integrity whereas CORS delivers highly precise positioning. Only in combination do they deliver the diversity of augmentation services required by of PNT users in Australia.

By recognising the synergies between SBAS, CORS and the National Broadband Network (NBN) we can create a sovereign PNT infrastructure providing Australia with an integrated capability to ensure full and secure access to the benefits of PNT2.0 and realise the considerable economic, societal and environmental benefits that such smart infrastructure can deliver.

Finally, it should be noted that this is not a new concept. The Australian GNSS Coordination Committee (AGCC) in their 2002 report *Positioning for the future* called for "*a multimodal approach to the application of GNSS meaning that the different range of users, for example aviation, marine, land transport or high precision users, can be serviced from a common infrastructure*".

Upstream Activities

Current State

Australia currently owns no space assets in the PNT domain. However, we are an advanced and innovative user of the space-based PNT assets being flown by other nations.

These foreign owned PNT space assets consist of dual-use global satellite navigation systems (GNSS) such as the United States Global Positioning System (GPS); regional navigation satellite systems (RNSS) such as China's Beidou; and satellite based augmentation systems (SBAS) such as Japan's MSAS. The table below outlines the major system providers and their current and planned GNSS, RNSS and SBAS.

	USA	**Russia**	**China**[7]	**EU**	**India**	**Japan**
GNSS	GPS	GLONASS	Compass	Galileo		
RNSS			BeiDou		IRNSS	QZSS
SBAS	WAAS	SDCM	MASS	EGNOS	GAGAN	MSAS

Table 1: Current and planned PNT space assets

GNSS provide the primary signals, free of charge, which can be used by GNSS receiving equipment anywhere on the earth's surface to derive position, navigation and timing services. RNSS do the same but over a limited portion of the globe. SBAS provide an integrity signal which alerts the GNSS receiving equipment if the GNSS or RNSS they are using exhibit a fault. SBAS are designed primarily for the safe navigation of commercial aircraft but have a wide range of other users, as SBAS also improves the accuracy of the user's positions. Further applications are found in areas including land transport, agriculture and the geospatial industry.

	1970s	**1980s**	**1990s**	**2000s**	**2010s**	**2020s**
GPS	◊		■	■	■	■
GLONASS		◊			■	■
BeiDou/Compass				◊	■	■

[7] China has started with an RNSS (BeiDou) which will be developed into a GNSS (Compass)

Galileo	◊	■	■
IRNSS		◊■	■
QZSS		◊■	■

◊ System Launch ■ Full Operational Capability (FOC)

Table 2: Operational status of GNSS and RNSS

The table above illustrates that in 2010, GPS is the only GNSS with Full Operational Capability (FOC). GLONASS is expected to have FOC by the end of 2010, and all the other GNSS and RNSS are predicting FOC before the end of this decade. All four GNSS and both RNSS will provide coverage over Australia.

WAAS, EGNOS and MSAS are also fully operational with the remaining three SBAS again planned for FOC before the end of this decade. When all have FOC, they will cover the airspace and territory of 15 Northern Hemisphere G20 nations. Of these systems, only the Japanese MSAS has potential coverage over Australia.

GNSS comprise constellations of 24 to 32 mid-earth orbiting (MEO) satellites. RNSS constellations are smaller (3-7) and can be both MEO and geostationary (GEO) satellites. SBAS only consist of geostationary satellites. An SBAS will typically broadcast from 2 or 3 GEO to provide area coverage and signal redundancy. MEO satellites orbit the earth at less than a 24 hour cycle, GEO satellites remain at the same point in the sky relative to the observer on the ground, and thus appear to be stationary.

Capabilities

Most existing SBAS satellites (including WAAS and EGNOS) use commercial GEO communications satellites with an additional L-band payload for navigation services.

Although Australia has no experience of building, launching or flying MEO navigation satellites, we do have significant and internationally recognised capability in GEO communications satellites.

Optus currently owns and operates five geostationary satellites (B1, C1 and D1-3) controlled from a dedicated facility in Belrose, NSW. They are also currently considering the next phase of their satellite business which potentially involves the launch of another satellite. The current design phase provides the opportunity to consider an additional payload and, from our understanding, an SBAS (L1/L5) payload could be added. This is the feasible because the SBAS payload is physically small, relatively light weight and also power efficient. We further understand that the established and experienced satellite control team situated at their Belrose satellite facility could be incrementally increased to provide the operational control capability required as part of the SBAS system/service. The team of professionals at Belrose are very experienced (average + 20 years) and are required to complete rigorous internal training as part of their ongoing internal accreditation.

Skills

Australia's academic sector, government research agencies and industries have, over many decades, been developing solutions to research both government and commercial needs and requirements dependent upon the data streams and services provided by communications, remote sensing and navigation satellite missions. Many industry and scientific sectors have benefitted from such capability, including meteorology, oceanography, natural resource management, minerals exploration, navigation services to air, and sea and land applications.

Aviation is an example of an industry sector which has developed a range of specific skills in GNSS. For example:

- Pilot training in GNSS theory, use of airborne equipment and licensing, endorsement and flying currency requirements;
- Engineers engaged to develop technical standards for radio frequency management, signal in space specifications and airborne equipment specifications;
- Avionics technicians trained in the installation and maintenance of airborne equipment; and
- Air Traffic Controllers trained in the use of GNSS technology for navigation and surveillance applications.

The skills base associated with space and satellite technologies in the university and research sectors is broadly spread across many departments. These include geosciences, geography, geospatial, a variety of engineering sciences, electrical and IT, and the physical sciences.

Future State

The *National Aviation Policy White Paper*, December 2009 (DITRD, 2009), acknowledges the International Civil Aviation Organisation (ICAO) Resolution 36-23 which resolved that Approach with Vertical Guidance (APV) should be implemented as either a primary approach, or as a backup for precision approaches, at all runway ends of all aerodromes serving aircraft with a maximum certificated takeoff weight of 5700 KG or more. This resolution included an implementation timing of 30% completion by 2010, 70% by 2014, and 100% by 2016.

The White Paper notes that implementation of APV is a major challenge for Australia and that one of CASA's first tasks will be to oversee the implementation of APV utilising barometric aided vertical navigation (Baro-VNAV) which should meet the ICAO APV introduction timetable of 2016 for airports servicing nearly all of Australia's major passenger operations.

Coverage of the remaining airports will be considered subject to the outcome of an SBAS review by the Department of Infrastructure, Transport, Regional Development and Local Government to examine the practicality, cost and timing issues associated with the establishment of such a capability in Australia.

The Airservices Australia corporate plan 2009-2014 cites a capital expenditure over the next 5 years of $898m and notes that the unprecedented increase in capital expenditure is due to some 60% of expenditure ($538.8m) being used to replace assets that have reached the end of their economic lives. Much of this cost comes from extending or replacing the network of terrestrial radionavigation aids.

The possible reduction of terrestrial radionavigation aids has not been determined in the context of an Australian SBAS. However, in its briefing paper to the Aviation Implementation Group (AIG), CASA noted that the expenditure for an Australian SBAS ($190-300m) is potentially less than the cost of maintaining the present system and that the cost of an SBAS might be partially offset by a reduction in the size of the current terrestrial radionavigation aid network.

It should also be noted the revenue base for aviation infrastructure funding comes predominately from commercial airlines which (with the introduction of Baro-VNAV) will have no need for SBAS services or equipment in their aircraft to use such services. Aviation is therefore unlikely to entirely self fund an SBAS.

However, existing SBAS in North America and Europe (WAAS and EGNOS) are used extensively by non-aviation users including marine and land transport, agriculture and the geospatial industry. For example, the EU estimates that of the 240,000 agricultural tractors expected to be fitted with GNSS by 2012 nearly 70% will be EGNOS capable[8]. As noted earlier, the economic benefits of EGNOS to agriculture alone are estimated at €6 Billion by 2030.

Resources

An investment of between $190-300 Million is required for an Australian SBAS depending on which options are selected. An example of the likely resources that would need to be deployed includes:

- Leasing two or three L1/L5 payloads on commercial geostationary communications satellites;
- Two or three master control stations to provide redundant operational control; and
- 20-30 monitoring stations located on the Australian continent and Island territories.

It should be noted that master control stations and monitoring stations could be shared with the national CORS infrastructure described later. This has the potential to reduce the total national PNT infrastructure costs.

Capabilities

As described earlier, Australia has many of the capabilities required to acquire, control and operate an SBAS. Specifically, an SBAS would deliver multi-modal, multi-application payloads which enable navigation, communication and surveillance technology with applications in:

- Aviation;
- Road, rail and maritime transport;
- Agriculture, forestry and fisheries;
- Emergency services management; and
- Search and Rescue operations.

Some of the additional capabilities which could be developed with this project include:

- Improved ionosphere modelling over the Australian continent;
- Enhanced space weather prediction and services;
- A future replacement for the AMSA DGPS service for marine users;
- The capacity to collaborate and expand the SBAS into a regional system covering New Zealand and the Western pacific islands; and

[8] European Space Agency, 2010

- Developing a credible presence in the Space domain for the purpose of strengthening multi-lateral and bi-lateral discussions for defence and commercial sectors.

Skills
The skills base which would be developed with this project is expected to be spread across all sectors: academic, research, government and industry. The university sector would, for example, be responsible for educating and training the coming generation of satellite engineers and technicians, as well as undertaking research and research training of highly qualified personnel. The research sector would address the needs for fundamental and applied research. The government sector would provide opportunities for management, oversight and control of satellite programs. The industry sector would develop commercial products and services which would ensure that future Australian industries would be well equipped to take advantage of future satellite/space opportunities.

The range of applications that SBAS can enable will require highly proficient and technically skilled personnel in disciplines such as:

- Application development;
- GNSS Experimentation;
- System design and system engineering;
- Simulation tools;
- Navigation and integrity algorithms;
- Turn-key critical subsystems development;
- Constellation design and control;
- Flight dynamics; and
- Critical software development.

Overall, an increased critical mass in the field of operations and control would better enable the sustainment of courses and training in this area and contribute to the enhancement of Space and PNT capability within defence, national security and more broadly in the civilian and commercial sector, creating of a cadre of operational space personnel.

Downstream Activities

Current State

Australia already has substantial existing terrestrial PNT infrastructure to support the activities of government and key economic sectors such as transport, mining, agriculture, civil engineering and the geospatial industry. However, to date, this infrastructure has been largely developed in an ad-hoc and uncoordinated manner by Commonwealth, state and private entities. We estimate that, collectively, Australia has already invested hundreds of millions of dollars in ad-hoc PNT infrastructure over the last ten years.

For example, the Commonwealth has invested in several PNT infrastructure projects including:

- AuScope, an NCRIS funded project to enhance Australia's ability to monitor the Australian continent will build over 100 GNSS Continuously Operating Reference Stations (CORS) by collaboration between Geosciences Australia and State governments.
- The Australian Maritime Safety Authority (AMSA) operates 16 CORS which broadcast an GPS augmentation service for coastal shipping around Australia as part of their international commitments to the safety of marine navigation;
- The National Measurement Institute (NMI) operates a GPS time transfer system and GPS integrity monitoring as part of their time and frequency dissemination activities; and
- Airservices Australia plans to install Ground Based Augmentation Systems (GBAS) at major airports to enable GNSS Landing System (GLS) approaches. Qantas has already flown over 2,000 GLS supported approaches into Sydney and the Civil Aviation Safety Authority (CASA) anticipates GBAS Category I (CAT-I) service approval in 2010. GBAS is expected to eventually support precision approach and landing to Category III (CAT-III) standards[9].

In addition, State Governments in Victoria, New South Wales and Queensland have all developed CORS networks to support their land management activities and to service additional users in agriculture, civil engineering, mining and the geospatial industry.

Finally, the private sector in Australia has invested in a variety of PNT infrastructure elements, including:

- Master control stations and monitoring stations in support of global commercial Wide Area Differential GPS services, for example, the Omnistar control centre in Perth;
- Coordinated CORS networks as operated for example by Smartnet AUS and GPS Network Perth;
- More than 4,000 privately operated GPS CORS in agriculture[10] alone; and
- Numerous GPS timing installations for synchronising energy and IT networks.

Resources

Although Australia has substantial installed resources in terms of terrestrial PNT infrastructure, the elements are largely uncoordinated. Further, much of this infrastructure, particularly the thousands of privately operated GPS CORS, is not capable of taking advantage of new satellite systems and signals.

For example, the projected GNSS 2020 "hotpot" (see below) in which users will have simultaneous access to more than 40 navigation satellites, substantially improving availability and accuracy, will only be available with newer GNSS receiving equipment, making much of the existing privately operated GPS CORS obsolete if their owners want to use all possible GNSS and RNSS signals.

[9] CAT I to CAT III are international standards for Instrument Landing Systems (ILS) where CAT-III is the most precise
[10] Submission by Control Traffic Farming to the standing committee on primary industries and resources, 2010.

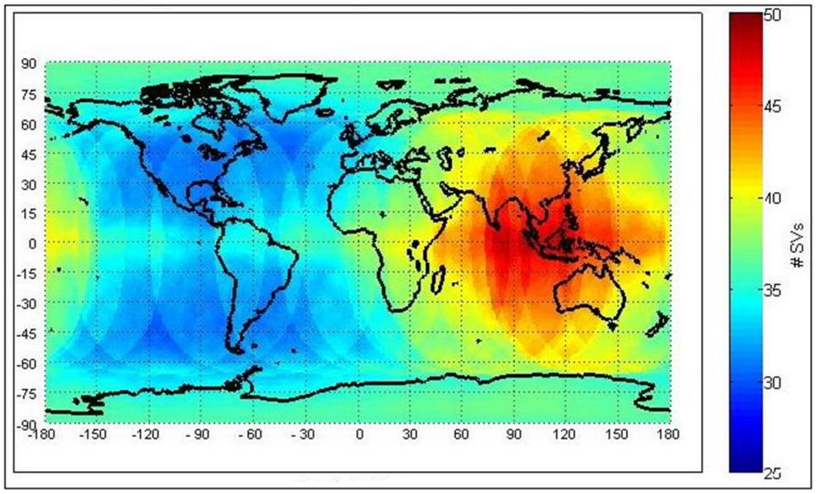

Figure 1: GNSS availability by 2020

Capabilities

Australia has public sector, private sector and research sector capability in downstream PNT infrastructure.

Public sector capability exists in Geoscience Australia, the Australian Maritime Safety Authority and Airservices Australia. All these organisations have experience in implementing PNT infrastructure projects including those described above.

CORS are also used by land management and natural resource agencies in all states and territories. Some areas have developed substantial capability in CORS network design and operation. For example, on completion of the entire Vicmap Position program, GPSnet will consist of approximately 102 GNSS CORS across Victoria. This infrastructure will allow for improved autonomous satellite positioning accuracy from 10-20 metres to a nominal state-wide real-time horizontal accuracy of +/- 2cm.

Private sector capability exists in the parallel development of privately operated CORS networks. These networks can use the data from publicly owned CORS, which opens up the possibility of new business models for the delivery of PNT services.

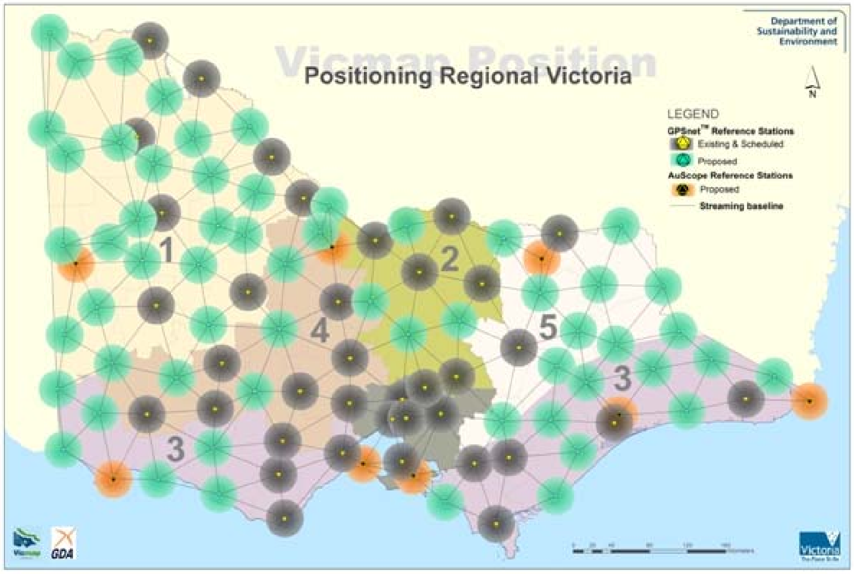

Figure 2: PNT Infrastructure in Victoria

Finally, the research sector in Australia has been internationally recognised for its science underpinning CORS networks. In particular, the Cooperative Research Centre for Spatial Information (CRC-SI) has been conducting research into CORS and terrestrial PNT infrastructure since 2007, with further funding through to 2018. The CRC-SI includes many of the public and private sector PNT infrastructure providers previously described (page 6), in addition to leading GNSS research universities such as UNSW and Curtin University.

Importantly, CORS networks provide infrastructure for research in their own right. For example, the AuScope CORS are used for geosciences, meteorological and atmospheric research.

Skills

In the field of satellite navigation research, the downstream skills base in PNT infrastructure is currently concentrated in the comparatively small university departments of geoscience, geography and geospatial engineering. In particular, the most challenging aspects of GNSS PNT – the high accuracy techniques based on carrier phase measurements and CORS infrastructure – are found in the schools or departments of surveying and geospatial technology. These departments educate undergraduate and postgraduate students in high accuracy GNSS and conduct all of Australia's research in this field.

Both private and public sectors have extensive skills and experience in the installation and operation of PNT infrastructure as described in the previous section.

Future State

As stated earlier, a national GNSS CORS would assist in the delivery of important national gateway, freight rail, freight road and public transport infrastructure projects. A national CORS would also boost the net present value of GDP in the construction, mining and agriculture sectors by between $6,675 and $12,636 Million by 2030[11]. For an investment of $300 million, the impact of a CORS network is comparable to the economic gains projected for the adoption of smart systems in energy, e-Health, irrigation and transport outlined in the recent Access Economics report on the economic benefits of intelligent technologies[12].

Coordinated national CORS infrastructure already exists in many G20 countries including the UK, Germany, France, Japan, South Korea and Turkey. In Australia, there have been several reports which have called for better coordination of CORS in Australia, as shown below.

<u>Farming the Future</u>

The role of government in assisting Australian farmers to adapt to the impacts of climate change. House of Representatives Standing Committee on Primary Industries and Resources, March 2010.

> ***The Committee recommends that the Australian Government, in conjunction with State and Territory Governments, establish a national Continuously Operating Reference Station network across Australia and regulate for signal compatibility between different GNSS.***

<u>Nation Building for the Information Age</u>

The economic case for governments leading the development of a national high accuracy positioning network. Lateral Economics, January 2009.

> ***Government leadership can make a huge difference – developing the capability at a small fraction of the cost of a similar network built without public involvement. But this cost saving pales into insignificance next to the economic benefits flowing from Federal Government leadership accelerating the roll out of a truly national network.***

<u>Economic Benefits of High Resolution Positioning Services</u>

Prepared for Victorian Department of Sustainability and Environment and the Cooperative Research Centre for Spatial Information. Allan Consulting, November 2008.

> ***At present, precision GNSS technology has been adopted to varying degrees by a number of industries in Australia, facilitated by numerous private networks. However, consultations undertaken over the course of this study suggest that***

[11] The economic benefits of high resolution positioning services. Allan Consulting, 2008.
[12] The economic benefits of intelligent technologies. Access Economics, 2010.

widespread adoption across a broader array of industries is being held back by the relatively high cost of accessing the technology, the lack of network coverage to deliver the service and the uncoordinated manner in which networks have been rolled out to date.

Resources

ANZLIC (Australia New Zealand Land Information Council) is the Spatial Information Council, representing all Commonwealth, State and Territory agencies that deal with spatial information, and is supported by the Australia Spatial Consortium. ANZLIC has already put forward a proposal to Infrastructure Australia (Department of Infrastructure, Transport, Regional Development and Local Government) for a national positioning infrastructure comprising up to 1,800 networked CORS for a cost approaching $300 million in early 2010.

A number of other resources could also be brought to bear on such a national CORS project, including the following possibilities.

- Numerous stations already installed by Commonwealth and State agencies and capable of being integrated into a national infrastructure could be incorporated;
- Existing private network operators and others who have experience in the different market segment could assist in developing an appropriate business model for delivering the PNT services;
- The National Broadband Network (NBN) initiative could potentially provide high speed data links between monitoring stations and master control stations, a requirement for both CORS and SBAS;
- Existing public and private sector operators of master control stations (e.g. DSE Victoria and Optus) could provide expert assistance in designing and developing the control segment for a national CORS and an SBAS; and
- Relevant experience in the national coordination of a spatial data infrastructure already exists in organisations such as Geosciences Australia, CRC-SI and the Public Sector Mapping Agency (PSMA).

Capabilities

The capabilities which would be created by a coordinated national CORS infrastructure include:

- Reducing cost of entry to high precision satellite positioning by eliminating the need for a user to acquire, manage and operate their own dedicated GNSS base station;
- National support for legal traceability of position;
- A unique international research capability able to analyse the performance of four GNSS and two RNSS on a continental scale;
- An educational and research base to support the development of next generation GNSS-based products and services; and
- A significant contribution to geoscientific studies, both on a national level as well as contributing to international geodetic initiatives.

Skills
A national CORS would provide a focus for increased R&D and educational activity in GNSS systems, techniques, products and services within universities, research organisations and collaborative programs such as the CRC for Spatial Information.

Risks / Vulnerabilities

In 2001 the Volpe report[13] highlighted the vulnerability of GPS to intentional and unintentional jamming and its potential impact in terms of safety, environmental and economic damage to the US economy should such a denial occur. In 2008 the US President's National Security Telecommunications Advisory Committee (NSTAC)[14] published a further report into commercial communications reliance on GPS. This report highlighted that GPS was embedded into many communications infrastructures to provide timing and synchronisation including wireline networks, wireless networks, satellite networks, cable networks, broadcast networks, enterprise networks and corporate networks.

In 2009 the General Lighthouse Authority (GLA) ran a series of GPS jamming trials in the UK. In a subsequent meeting held at the National Physical Laboratory in the United Kingdom on the 23rd of February 2010, Sally Basker, Director of Research & Radio Navigation at GLA, stated:

> ***"GNSS interference is a real and present danger. It is probably more widespread than generally assumed, and it is here to stay. We can harden our GNSS systems with improved receiver and antenna design, but this will mitigate only some interference, not all. The problem is cost. Cheap — and vulnerable — GNSS receivers will inevitably find their way, unseen, to the heart of our critical infrastructure. We need resilient positioning, navigation, and timing based on independent and complementary systems and sensors. Demonstrating independence is vital but not necessarily straightforward, and true independence costs money. The greatest challenge is helping policymakers understand the risks of relying on vulnerable systems and the need for resilience."***

Australia is no less dependent on GNSS than the US and UK. In 2002, the Australian GNSS Coordination Committee (AGCC) report, *Positioning the future,* documented the wide variety of GNSS applications in Australia and their importance to transport, primary industries and other sectors. Although the AGCC ended in 2006, their legacy includes several important outcomes, including:

- Licensing of the GNSS spectrum;
- A ban on GNSS jammers since 2004;

[13] Vulnerability assessment of GPS. Volpe, 2001.
[14] NSTAC report on the commercial communications reliance on GPS. NSTAC, 2008.

- Clarification on the evidentiary use of GNSS e.g. commercial fishing vessels inside prohibited zones; and
- Recognition of the vulnerability of GNSS and the importance of educating both industry and policy makers on this topic.

Although these actions have gone some way to protect PNT1.0, they are not adequate to ensure full and secure access to PNT2.0. An Australian SBAS and national CORS network, however, could provide an independent sovereign PNT infrastructure which has the capability to detect both intentional and unintentional jamming and interference of GNSS signals in a timely manner. This would give both users and authorities time to activate backup plans and mitigation strategies.

Self-Sufficiency

Like PNT1.0, PNT2.0 will be based on the free services broadcast by foreign controlled GNSS and RNSS. In this regard, it is unrealistic to expect Australia to be self-sufficient.

However, in regards to an SBAS and national CORS network, forming the foundation of a sovereign PNT infrastructure it is essential for Australia to be self-sufficient in this aspect.

As demonstrated earlier, Australia has the resources, capabilities and skills to plan, control, operate and maintain both an SBAS (based on additional payloads to GEO satellites) and a national CORS network.

A sovereign PNT infrastructure configured to utilise different combinations of GNSS and RNSS would provide Australia with a flexible capability to maintain critical PNT services if one or more of the six space systems became unavailable. Further, the integrity and reliability of PNT services to users is greatly enhanced through having a national PNT capability that uses *all* available GNSS/RNSS systems and signals.

Sustainability

Sovereign PNT infrastructure should be considered an essential element of Australia's national public infrastructure.

Ultimately, sustainability of a sovereign PNT infrastructure would depend on market forces and the downstream demand for such services. There is strong evidence of the importance of PNT to Australian industry. This includes:

- A report commissioned by the Victorian Department of Sustainability and Environment which found that in 2007 the benefit of precision GNSS to the agriculture, mining and construction sectors in Australia was between $829-1486 million[15]; and

[15] The economic benefits of high resolution positioning services. Allan Consulting, 2008.

- A study commissioned by the Queensland Department of State Development calculated that in 2006 the GNSS sector generated $350 million in goods and services in the state[16].

Supporting evidence of the indirect impact of PNT can be drawn from a study into the value of spatial information (the product of most non-consumer PNT applications) commissioned by ANLIC and the Cooperative Research Centre for Spatial Information[17]. This study found that spatial information:

- Contributed to a cumulative gain of between $6.43 billion and $12.57 billion in Gross Domestic Product (GDP)– equivalent to 0.6% and 1.2% of GDP respectively;
- Increased household consumption by between $3.57 billion and $6.87 billion on a cumulative basis;
- Increased investment by between $1.73 billion and $3.69 billion on a cumulative basis;
- Had a positive impact on the trade balance. Exports were between $1.26 billion and $2.30 billion higher than they would otherwise have been, and imports were between $1.18 billion and $2.23 billion higher than they would otherwise have been; and
- Real wages were by between 0.60% and 1.12% higher than they would otherwise have been.

Further, the Australian small and medium enterprise (SME) sector has a strong history of innovation in GPS applications. Many of the early pioneers are now part of multi-national companies servicing global supply chains. Some examples include:

- Beeline Technology (now part of Hemisphere GPS, Canada) founded in 1997. The first company in the world to commercialise GPS auto-steer systems for Agricultural machinery.
- Tritronics (now part of the Hexagon Group, Sweden) pioneered the use of precision GPS for heavy earth moving machinery in Mining during the 1990s.
- KEE Technologies (now part of Topcon, Japan) were amongst the earliest companies globally to use GPS for precision agriculture systems.
- GPS Online (part of Industrea, Australia) pioneered the use of low cost GPS and motion sensors for driver adherence safety systems in light vehicles around mine sites.

The companies all followed a similar path. Namely, they are all small entrepreneurial Australian SMEs, they have proximity to primary industry customers, they were first-to-market with an innovative solution, and they are all now integrated into a larger company with global reach and supply chain.

However, that is not the only story. There exists a strong and vibrant independent SME sector in Australia developing GPS and GNSS applications for a wide range of markets. Some of these companies include:

- Alive Technologies, who use GPS as part of e-Health solutions;
- GPSports, who incorporate GPS into performance monitoring equipment worn by professional athletes and sports people;
- Snowsport Interactive, who develop systems for tracking skiers around ski resorts;
- Sirian Pty Ltd, who use GPS to activate multilingual tour commentaries on buses allowing customers of many nationalities to enjoy the experience together; and

[16] Building an internationally significant presence in the GNSS marketplace. Position One Consulting, 2007.
[17] The impact of modern spatial information technologies on the Australian economy. ACIL Tasman, 2008.

- IntelliTrac (a BRW Magazine Fast 100 company 2007 and 2008 placing in the top 20), who provides a broad range of in vehicle and personal GPS Tracking, Navigation & Mobile Workforce Solutions for both Fleet Management, Automotive Security, Personal Tracking and Telematics.

The Queensland Government GNSS Industry directory identifies 40 companies in that state involved in GNSS application development with 250 private sector R&D personnel. There is good anecdotal evidence to suggest an equivalent application development capability exists in other states.

It is clear from the evidence above that a vibrant PNT user community already exists in Australia and forms the basis of a sustainable market for sovereign PNT services.

Benefit to Community

Secure and dependable PNT services have a wide range of community benefits, including:

- Personal navigation on land, sea and air;
- Knowing the whereabouts of dependents such as children and elderly parents;
- Providing guidance systems for the disabled such as the visually impaired;
- e-Health solutions such as monitoring systems for Alzheimer's patients and other vulnerable groups;
- Supporting emergency services and search and rescue activities; and
- A learning tool to teach students about geography and other subjects requiring spatial analysis.

Many of these uses are part of the Location Based Services (LBS) market which has an estimated global value of just over US$2 Billion in 2009[18] with North America, Asia Pacific (including Australia) and Japan the largest markets.

LBS use connected location-enabled smartphones to deliver consumer services based on the geographic position of the user. A simple example is street navigation. Other examples include tracking the whereabouts and safety of children and other dependents.

LBS in Australia have historically used positioning derived from cell towers rather than satellite signals. However, with 25% of smartphones already shipping with GPS[19] and predictions from companies like Nokia that GPS will eventually be in every phone[20], this situation is likely to change in the future.

A notable additional benefit of LBS is that as individuals become more efficient in their travel, they reduce their carbon footprint.

[18] Consumer location based services. Gartner, 2010.
[19] GPS Business News. 31st May 2010.
[20] ZD Net. 21st July 2007.

Related Policies

The discussion of sovereign PNT infrastructure crosses several Commonwealth agencies and jurisdictions.

The formation of the Space Policy Unit (SPU) within the Department of Innovation, Industry, Science and Research is an important portfolio with regards to PNT infrastructure. In addition, the CRC for Spatial information is a primary source of capability and skills in CORS network research, development and implementation.

The Department of Defence has deep connections with the US GPS program and capability in PNT infrastructure through agencies such as the Defence Science and Technology Organisation (DSTO).

Within the Department of Infrastructure, Transport, Regional Development and Local Government, PNT Infrastructure is highly relevant to Australia's international obligations in regards to the safety of navigation for both Aviation and Shipping. Relevant agencies include Infrastructure Australia, the Civil Aviation Safety Authority (CASA) and the Australian Maritime Safety Authority (AMSA). The requirement for an SBAS is highlighted in the Aviation White paper of 2009.

PNT infrastructure is also relevant to the Department of Agriculture Fisheries and Forestry. The establishment of a national CORS network was one of the recommendations of the Standing Committee on Primary Industries and Resources, March 2010. Relevant agencies include the Australian Fisheries Management Agency (AFMA), the Cotton Research and Development Council (CRDC) and the Grains Research and Development Council (GRDC).

The Department of Resources, Energy and Tourism through Geosciences Australia and ANZLIC (the Spatial Information Council) is both a strong centre of capability and skills in CORS networks and also a source of expert knowledge on their economic, societal and environmental benefits. ANZLIC in conjunction with the Australian Spatial Consortium (ASC) presented the proposal for a National CORS network to Infrastructure Australia in 2009.

The Department of Broadband, Communications and the Digital Economy has a critical role to play in the development of PNT infrastructure through spectrum licensing and management (ACMA) and in the relationship of a sovereign PNT infrastructure to the National Broadband Network (NBN).

Finally, the Department of Foreign Affairs and Trade has a significant role to play in terms of both multi-lateral and bi-lateral agreements with GNSS and RNSS provider nations. An example of potential multi-national engagement is through the United Nations Office for Outer Space Affairs (UNOOSA) International GNSS Committee (IGC). An example of existing bi-lateral engagement is the US-Australian cooperative relationship on GPS and space-based PNT through a Joint Delegation Statement signed in 2007.

Other Areas/Opportunities

As Australia will be able to "see" some of the next generation GNSS/RNSS signals before North America and Europe, there is the opportunity to study these signals to determine their utility for a variety of GNSS PNT applications. Some of these include:

- Local adaption of imported GNSS-based products and services;
- Development of niche products such as special-purpose (or customisable) GNSS receivers, data processing software, CORS systems, and commercial and non-commercial services;
- Assist neighbouring countries in the Asia-Pacific region to establish their own CORS infrastructure, and to adopt new GNSS-based products and services to address their own local requirements;
- Establish a solid education base for undergraduate and postgraduate students education and training for the region, taking advantage of our developed country status and English language skills;
- Development of "shared" GNSS services with governments and the industry sector in neighbouring sector.

Summary

Sovereign Positioning Navigation and Timing (PNT) infrastructure should be considered an essential element of Australia's national public infrastructure.

The Global Positioning System (GPS), representing the first generation of a global Positioning, Navigation and Timing utility (PNT1.0), has become a critical component of our transport, energy and communications infrastructures along with establishing itself as a key smart technology for increasing the productivity of our ports, mines, farms and construction sites.

The substantial terrestrial PNT infrastructure which has evolved to support GPS users in Australia has grown in an ad-hoc and uncoordinated manner with only a few policy initiatives in the area of spectrum licensing and protection. The result is that individual commonwealth, state and private sector entities have established a patchwork of PNT1.0 infrastructure across Australia of varying capability, often duplicated and with no standards.

The full operational capability of the Russian GLONASS system, expected by the end of 2010, marks the dawn of the second generation of PNT (PNT2.0) which by the end of this decade will comprise an interoperable "system of systems" from the US, Russia, EU, China, India and Japan.

With appropriate sovereign PNT infrastructure in place, PNT2.0 could bring substantial benefits to Australia including an increase of at least $6.6 billion in GDP by 2010, safer and more efficient airspace and transport networks, significant community benefits and enhanced capabilities for measuring the impact of climate change.

Whereas Australia has been a leader in utilising PNT1.0 notably in the transport, agriculture, mining and geospatial industries, without coordination and investment by government in the infrastructure to support PNT2.0 we will inevitably fall behind other G20 nations in the effective and efficient utilization of this important global space-based utility.

Compared to PNT1.0, PNT2.0 therefore requires a much greater degree of whole-of-government response along with an investment in smart infrastructure.

Recommendations

1. Establish a permanent unit within government with responsibility for coordinating space related policy including Positioning Navigation and Timing infrastructure. As a precursor the Space Policy Unit should consider the following actions:
   - Develop a PNT Skills Strategy;
   - Work with the Space Council to promote the opportunities of PNT2.0 to applicable stakeholders; and
   - In conjunction with relevant agencies, develop a strategy for multi-lateral and bi-lateral engagement with GNSS and RNSS providers.

2. That the Commonwealth invests between $500-600 million in coordinated, national PNT infrastructure comprising a Continuously Operating Reference Station (CORS) network and Satellite Based Augmentation System (SBAS) designed to be fully compatible with PNT2.0. Some of the immediate actions which should be undertaken include:
   - Form a steering group, chaired by the Space Policy Unit, to engage key stakeholders and formulate a national PNT strategy;
   - Commission a study of the existing public and private sector investment in PNT1.0 infrastructure and the benefits of a more coordinated approach to PNT2.0 including the economic benefits of an SBAS to the civil community; and
   - Engage with Infrastructure Australia to bring forward a national PNT infrastructure development plan.