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Global Navigation Satellite System Augmentation Models Environmental Scan

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Canada

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Environmental Scan

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Executive Summary

Introduction and Context

This study provides a high level environmental scan to investigate the role Government and industry play, in terms of collaboration and investment, in supporting the implementation of Global Navigation Satellite System (GNSS) augmentation systems. Augmentation systems improve the accuracy, reliability, and integrity (or availability) of position information through the integration of external information into the calculation process. The study is focused strictly on the civilian sector: military applications are specifically excluded.

The context in which the study has been done is complex and rapidly changing in terms of the technology, resulting applications, and business models used for service delivery within the private and public sectors. This study report places the augmentation models in the appropriate context of a combination of government and industry activities. Particular attention has been paid to commercial services because of their growing importance and visibility. Given the competitive nature of the industry, financial information from commercial suppliers has been difficult to access since the suppliers are understandably unwilling to share financial information. For this reason estimates provided here are built up from an amalgam of sources and are presented as “order of magnitude” values.

GNSS Augmentation Services in Canada: RTK, PPP, DGPS and WAAS

GNSS augmentation services are generally classified under two broad categories. They depend on whether or not users apply a differencing approach to combine observed satellite ranges and the physical point selected to geo-reference the computed corrections. Implementations with differencing and corrections referenced to a ground control station are known as Ground Based Augmentation Systems (GBAS), which include RTK and DGPS. Implementations without differencing and corrections, referenced to point on the navigation satellite, are known as Space Based Augmentation Systems (SBAS), which include PPP and WAAS-type services. The difference between PPP and RTK has been simply explained using the following quote from Chassagne (2012):

RTK: “Tell me the precise location of your reference station and I will tell you the precise location of your mobile receiver.”
PPP: “Tell me the precise location of the navigation satellites and I will tell you the precise location of your mobile receiver.”

Figure 1 provides a graphical representation of the augmentation services provided in Canada: Real Time Kinematic (RTK), Precise Point Positioning (PPP), Differential GPS (generally thought of as coastal DGPS) and the Wide Area Augmentation Service (WAAS), for aviation.

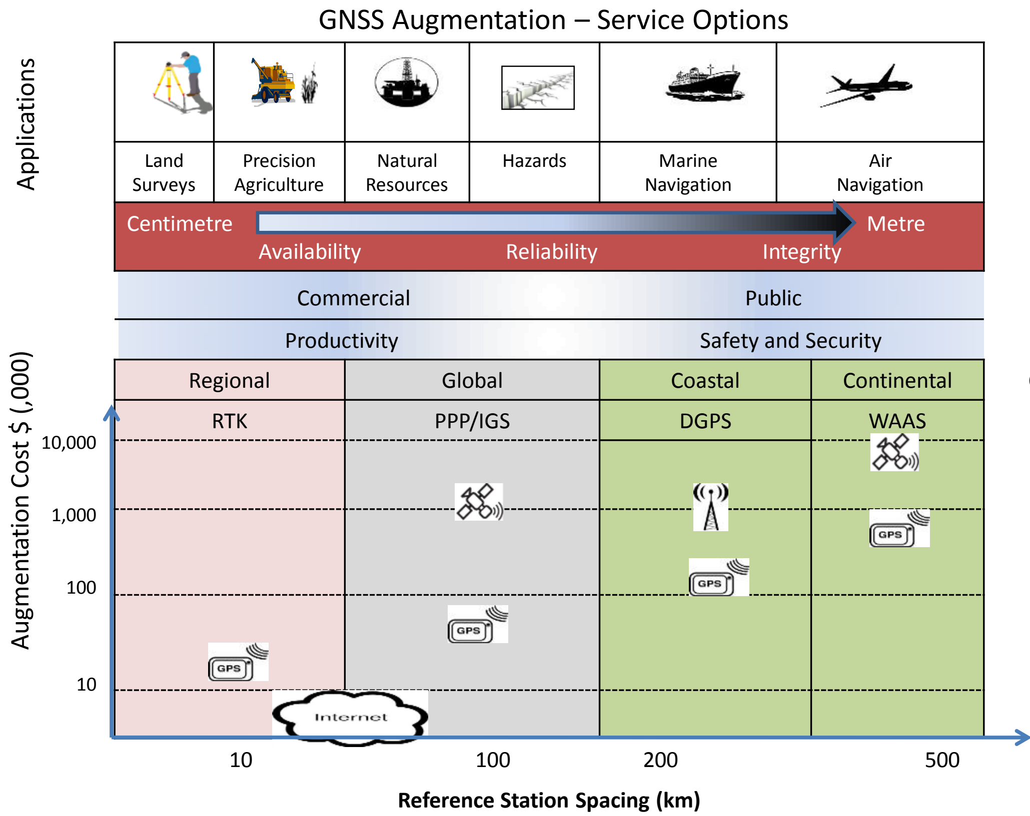

Figure 1: GNSS* Overview *(Source: Provided by P. Heroux, March 2015)

The top two rows illustrate the users of the specific services – from land survey to air navigation. The next row shows the decrease in precision as one moves across the various augmentation services. The fourth row indicates that RTK and PPP augmentation services are largely provided in Canada by the commercial sector (although some RTK networks are operated by governments), while DGPS and WAAS are provided as a public service. As one moves from the RTK to WAAS, one also sees a shift from the benefits that accrue – from improved productivity with RTK and PPP to public safety for DGPS and WAAS. As one moves from RTK to WAAS there is a shift from availability to integrity. For example accuracy of a few centimeters is required for land survey, but accuracy of a few meters is most often sufficient for marine and air navigation. Integrity is the level of trust that can be paced on a system – more important for air navigation applications than for machine guidance in a farmer's field.

Figure 1 also shows that as one moves from RTK to WAAS, reference stations are placed farther and farther apart – from 10 km for RTK to 500 km or more for WAAS. As station separation increases so do the costs of the stations as they usually have more redundancy on-site. The small image of a satellite under both PPP and WAAS depicts the role of satellites in providing a dedicated satellite communication channel – a feature that adds to the cost and capabilities of those two approaches. The tower under DGPS underscores the use of ground-based beacons in that service. It should also be noted, as is discussed in the body of this report, that as one moves left to right from regional to global/continental services, there is increased uncertainty in estimated costs. Some of this uncertainty is associated with getting the data to users. Obviously, Internet costs are much less than those of networks of ground beacons or dedicated channels over communication satellites, but may not suitable for high integrity safety of life applications. Full details on costing are provided in Section 4.8.

The twelve major GNSS augmentation services used in Canada, plus one municipal service, are placed in the global context in Section 3 and summarized in Table 1 in terms of their coverage, how they function, precision, sectors served and whether they are private or public sector.

Uses in Major Economic Sectors

The next major part of the study, presented in Section 4, summarizes how augmentation systems are used in five major economic sectors: transportation, natural resources, public safety and emergency management, science, and land survey. While the focus is on augmented GNSS in Canada, the world-wide situation and non-augmented uses are also summarized to provide context.

Transportation is likely the area of GNSS best known by the public who use in-car navigation systems, although most consumer products do not rely on augmented GNSS as defined for this study. In the near term the first use of augmented GNSS in road transportation will likely come with automated toll-road collection systems – where more precision is required to determine if a vehicle is on the toll road or an adjacent road. In the longer term autonomous, or driverless, vehicles may dramatically change the use and importance of augmented GNSS in road transportation.

Despite the limited use of augmented GNSS for intelligent vehicle navigation, transportation is the sector where it most directly affects Canadians. Air navigation depends on the GNSS Wide Area Augmentation System (WAAS), built by the USA at a cost of over $4 billion, and which Canada uses. For maritime users, the Canadian and US Coast Guards operate the Differential GPS Service to provide better information for harbor entrance and approach navigation. The Canadian part of the system, operational for over a decade, requires replacement at a cost estimated to be about $28M, with an annual operating cost of over $400K. In the future one may see machine assisted docking in marine transportation.

Augmented GNSS is not yet routinely used in rail transportation. Rail transportation is problematic for GNSS signal tracking because of challenging environments – including tunnels, covered stations – and a strict regulatory environment. Augmented GNSS is primarily used with other information when applied to rail transportation in trackside signaling. Eventually it is expected that in-cab signals will replace track-side systems.

Natural resource applications reviewed include agriculture, mineral and oil exploration and development, environmental studies, and forestry. Almost every augmentation system, whether RTK- or PPP-based, plays in at least some way to one or more of these areas, although some commercial services would appear to be more focused on one specific activity. The major application is machine guidance – whether in precision agriculture, mining or construction. Augmented GNSS in agriculture is an important and growing market in North America, Europe and Australia. More than 70% of the farm equipment sold in Europe has some form of precision agriculture "inside." The number of agricultural users in North America, Europe and Australia has been estimated in the millions. In Canada, agricultural applications have driven how at least one of the major commercial providers has scoped their system's 24/7 capabilities to achieve high redundancy. The private sector's RTK network in Canada has been estimated to have cost about $19.5M to install, with annual operating costs of approximately $3.3M.

The global market for precision agricultural services is projected to grow at 13% per year to over $6B by 2022. Applying results from Australia we project an impact in Canada for grain farmers from about $250M to $390M in 2013, and double that by 2020. Using the same relative statistics for dairy and beef farming leads to similar benefits in the tens of millions of dollars, growing to hundreds of millions by 2020. While used in some mining activities (machine guidance) and forestry (such as for road construction or selective harvesting), and for environmental sampling, these applications are minor compared to agriculture.

The third sector analyzed is public safety and emergency management which includes policing, ambulance or emergency services, and issues involving public health. Most applications associated with this sector are met by non-augmented GNSS. However, there are several high profile applications such as more precise dispatching of emergency vehicles and first responders, precise water level measurements associated with flooding, and forensic studies by police. The near future may see UAVs dispatched over disaster areas to acquire imagery or provide communications, while in the longer term studies in Japan suggest that it may be possible to predict earthquakes using augmented GNSS. If earthquakes can be predicted, the potential benefits on Canada's west coast and Quebec City regions would be measured in the hundreds of millions of dollars or more for each major event.

The fourth sector reviewed was science, which was originally taken to mean application of augmented GNSS in geodesy and geosciences– measuring crustal dynamics and the like. However, augmented GNSS is widely used and widely applied to a much broader range of research topics including earthquake prediction, plot trials in agriculture, soil science, and a variety of environmental topics. The published information on the costs of running science sites was used to help estimate the investments that have been made in augmented GNSS technology in Canada. A total of about $3M in the network infrastructure, which costs about $400K annually to operate, is estimated to have been made, mainly by federal and provincial governments. The manner in which GNSS data and resources are shared by the scientific community world-wide is said to be one of the best examples of international cooperation in science.

The final economic sector reviewed was land survey. Originally seen to be part of natural resources, land survey was treated as a separate sector based on the importance accorded the market by commercial suppliers who were interviewed. With the precision required by law, only augmented GNSS can meet the needs of land surveying. Applying the results of an Australian study to Canada suggests that the economic benefits of augmented GNSS to the land survey community would be on the order of $45M, growing to as much as $150M by 2020.

Investment in GNSS Augmentation Services Used in Canada

Considering the estimated impacts of augmented GNSS on the economy of Canada, the investments by government (and industry, for that matter) have been modest. The federal and provincial governments have invested a total of about $3M in the network infrastructure, which costs about $400K annually to operate. In addition the replacement cost for the Canadian Coast Guard Next Generation DGPS has been estimated at about $28M, with operating costs of about $420K per year. The private sector's RTK network in Canada has been estimated to have cost about $19.5M to install, with annual operating costs of approximately $3.3M.

A number of assumptions have been made to estimate the cost to build and implement a PPP global service. Obviously, such a service is meant to serve the global community, not just Canada. To do the research, build the software and hardware systems and then implement and market a service has been estimated to cost almost $14M, with an annual operating cost of about $3M. These are order of magnitude estimates. There are at least three major commercial suppliers of PPP services, with an assumed investment totaling between $30M and $40M.

Role of Government

The role of government is considered from several perspectives in this study. The various activities of the Federal GNSS Coordination Board are outlined as are the current and future roles of several Federal departments and agencies. One of the most important roles for government as seen by industry is the validation of the technology and its application. The role of government in Canada can be contrasted to that in the USA on the basis of the number of Continuously Operating Receiving Stations (CORS) and their cost. Using the same rules of thumb as are used to estimate Canada's investment, the 1500 CORS operated by or for government agencies in the USA (excluding Coast Guard and FAA stations) represent an investment of $53M, almost twenty times that of equivalent Canadian agencies. That an industry representative in the USA stated that they are selling services in states where the state data are free, says something about how government services are perceived in that country – they are not seen as being as reliable. The same representative noted that Canada's government contributions have to date been directed mainly towards providing validity to the commercial services – and the government does not compete with the private sector. The role and importance of government activities that contribute to the maintenance of a Global Geodetic Reference Frame (GGRF) have also been recognized in a recent resolution adopted by the UN General Assembly – which Canada co-sponsored (United Nations, 2015).

Regional Comparison

The last substantive part of the report compares the situation in augmented GNSS in North America, Europe and the Asia Pacific Region. The differences are real and, in some cases, substantial as summarized in Table 8. The main points of comparison are on:

- When the technology was first embraced (first in North America, then Europe and Asia);
- The support of government (highest in North America and Europe, variable in Asia);
- Varying levels of development (highest in the USA and Canada, Western Europe, Australia, Japan and China);
- Degree of government control (low in North America, medium in Europe, mostly high in Asia);
- The level of fragmentation between the countries in the region (highest in Asia, lowest in North America);
- Level of investment of individual countries (highest in USA, Russia, China, Japan, parts of Europe);
- The number of major countries in the region and their relative strength (USA balances Russia and EU in Europe. Because of China, Japan and India**,** Asia is becoming more important);
- The level of apparent trust between countries (highest in North America, lowest in Asia);
- The perceived role of the military (highest in Asia, lowest in the EU);
- Clearly stated military involvement in satellite control (high in North America, zero in Europe, zero to high in Asia); and
- The role seen for local industry (high in Canada, USA, and EU, growing in China).

Trends in Augmented GNSS

A number of trends are identified in both the technology and services. It is expected that hand held mobile devices will be more powerful and will assume more of the work load. Cell phones and rovers will continue to be widely used. These aforementioned factors will lead to lower costs, more recreational use and to increased use of augmented services where such use is now limited, most notably in developing countries. Contributing to this growth will be an expected growth in support of GNSS augmented services in less developed countries by governments in developed countries. Over the next fifteen years there will be a maturing of the market for augmented GNSS services with higher penetration in areas where it is now used. More income will come from subscriptions for both professional users and consumers. Consumers will begin to buy services – or get access on some "Google-like model" – i.e. a third party will pay for access based on a different monetization scheme.

Governments' role will continue to be important for the foreseeable future: governments will continue to provide the space component. Only governments will have the resources and desire to launch, maintain and improve GNSS satellite constellations. This is the infrastructure that all users of GNSS depend upon, much like commerce depends on the maintenance of most roads and highways being done by government. Governments will be the primary custodian, supporter, and protector of the infrastructure in the future, including providing control and confirming accuracy of the base upon which the entire system rests. Governments will work in areas where there is limited to no commercial interest (e.g. far north in Canada). Government involvement (and ultimate control) will have to continue for security and public safety reasons – especially in Asia, areas not served by industry, and those areas prone to disasters such as earthquakes and flooding. However, as pressures on government budgets increase, governments (states in the USA) may stop operating RTK networks, which some claim that the states do in competition with industry. Even in areas where the private sector is providing ground infrastructure, Government will have to continue to provide a "bare bones" presence and expertise in the event of a cataclysmic disruption to the private sector network. This seems to have been the approach adopted by Canada.

There will be better accuracy, improvements in reliability, and diversification of use – world-wide. Additional satellite systems plus GPS modernization should lead to improvements in satellite availability and accuracy. We expect that Precise Point Positioning will become more important. There will be a further blurring between geodetic applications, that is precise applications, and consumer applications, as the latter will be provided with more sophisticated options. Sensor fusion will truly emerge – with GNSS, INS and vision-based sensors leading the way towards ubiquitous positioning.

More countries will join the International Committee on Global Navigation Satellite Systems (ICG) and that Committee will be an even more important window on the field. This will be especially important with the growth in the number of GNSS constellations since there will be a need to calibrate inter-constellation biases and support the realization of a consistent reference to facilitate the monitoring of global change.

Conclusion

The role of government has, in certain ways, continued on the same path as in the past, and has changed quite remarkably in other ways. Governments are the only ones building and financing the space component and governments continue to support basic geodetic research. That research is more likely to focus on a societal need (tsunami and earthquake prediction, for example) rather than on more esoteric topics (pole movement, for example). There has been a useful lesson, however, in the area of geodesy. What began as esoteric research on movement of the earth's crust has, with augmented GNSS, is leading to a better understanding of earthquake precursors. Indeed, one Japanese scientist has shown the ability to predict earthquakes.

It is also clear that governments have a role in providing the base or control on which the entire GNSS services business rests. This is in part related to the issue of trust: governments tend to be more trusted than private sector groups when it comes to geospatial information. While the role of government in providing the space infrastructure continues, there are new models emerging for government involvement in the ground segment. These models vary considerably from country to country depending upon the country's geography, the stage of development and the degree to which the military or security forces control access to the information.

In some cases the bulk of the ground segment is still paid for by government. In some cases this is a hold-over from when the military controlled mapping or because of security and public safety concerns in the country. In the case of China and Japan, it may also be that governments are reluctant to put technology important for disaster response and mitigation into private sector hands. In less developed countries like Bangladesh government is the sole provider of the ground segment (and a late provider at that) since there is virtually no private sector with the justifiable business case to support such services. In still other countries Public Private Partnerships are used – a justifiable business case has been developed.

In Canada, the USA and Australia the private sector provides a significant part of the ground infrastructure in the form of thousands of CORS stations. But in all three countries there are large swaths of the country where the private sector cannot justify the expense of supplying the ground infrastructure – there is no market for services. These areas must continue to be served by government. A case can also be made for the government to continue to provide a modicum of involvement in areas well-served by industry as a back-up and to provide control and a stabilizing influence. However, one might also argue that there is significant and perhaps needless overlap between government and private sector services in some parts of the USA.

The total investment in augmented GNSS by the government sector in Canada appears to have been about $ 32 million, including the projected Coast Guard investment, but excluding Nav Canada. The investment by governments in Canada, excluding the marine and aviation navigation, is considerably less than what has been invested in the USA – 1/20 as much, or perhaps even less. The private service sector has invested about $20 million, not including PPP. These numbers do not include the many millions of dollars spent on system engineering and the technologies needed to use the services – such as machine guidance systems on farm equipment or construction equipment, navigation systems on aircraft, or survey equipment. Given the economic impact of these technologies on Canada, never mind security and governance issues, this would appear to be an excellent and necessary investment of government resources. The investment by industry in PPP world-wide has been roughly estimated to be on the order of $50 million.

The technology is changing rapidly and GNSS augmented services are growing in both their use and importance. New uses will lead to the need for new policies. Some governments are developing advisory structures, strategies and plans to ensure that their countries are able to both keep up with the technology and its application for the benefit of the people. Australia seems to be a useful model in that respect.

The final conclusion is that the Canadian government will have an important but ever changing role to play in Global Navigation Satellite Systems to ensure that:

- The safety and security of all Canadian's is assured:
- Our resources are properly monitored and managed; and
- Our industry can remain competitive in the many areas touched by GNSS augmented services.

Now would appear to be a good time to ensure that the advisory structures, strategies, and plans are in place to ensure that Canada benefits to the maximum extent possible from augmented Global Navigation Satellite System services.

1. Introduction to the Study

This study provides a high level environmental scan to investigate the role Government and industry play, in terms of collaboration and investment, in supporting the implementation of Global Navigation Satellite System (GNSS) augmentation systems. The study is focused strictly on the civilian sector: military applications are specifically excluded.

The context in which the study has been done is complex and rapidly changing in terms of the technology, resulting applications, and business models used for service delivery within the private and public sectors. As was noted in the Request for Proposals, "*GNSS augmentation systems are proliferating as many countries need to support critical activities such as navigation and fleet and asset management in key industries such as airlines, trucking and railroads. Further, augmentation will be required to support emerging applications such as machine guidance and autonomous navigation. The Canadian Geodetic Survey requires a scan of the role Government currently plays, in a global context, towards the provision of GNSS augmentation to ensure that Canada has the technical infrastructure necessary to enable implementation and innovation in Canada.*"

This study report provides the required scan, placing the augmentation models in the appropriate context of a combination of government and industry activities. Particular attention has been paid to commercial services because of their growing importance and visibility. Furthermore, the economic value of the services they offer across the economy – from agriculture, resource development and management, on to transportation and public safety – has been clearly demonstrated in studies elsewhere. (ACIL Allen, 2013) However, commercial firms are not willing to share detailed information on costs or income. Indeed the only income number obtained for a GNSS augmented service was from a media report – Veripos was said to have had annual income of $45M in 2013 and its income was also reported after its acquisition by Hexagon (Murfin, 2014; Hexagon, Accessed 3/10/15). As a result of the reticence of industry to provide cost and income figures for augmented GNSS, a more generalized approach to costing was adopted after consultation with the client. The scan draws on a combination of a literature review (including sources on the Internet), interviews with key players, responses to e-mails asking for information, and prior experience of the Kim Geomatics team members who have contributed to this report.

Section 2 provides additional information on the background (drawn in part from materials provided by the client). Section 3 gives the required list and review of major services world-wide that are used in Canada or where experience is relevant to Canada. Section 4 delves into more detail on applications and investments for augmentation systems related to the four major economic sectors targeted by the client: Transport, Natural Resources, Public Safety and Science. Section 5 addresses the trends that have come to the fore in the course of conducting this study. Of particular interest in this regard is the critical role seen for government by industry players. Section 6 examines what is being done in the United States and Canada in comparison to Europe and Asia-Pacific Region, with special attention to Australia.

2. Background

The background to the study given in the Request for Proposal and repeated verbatim[1] below provides a useful point of departure.

[1] The verbatim text appears in italics. Clarifications are given in standard text (not italicized).

“*GNSS augmentation is the term commonly used to refer to systems that provide information to improve the precision and integrity of GNSS positioning solutions. An augmentation system typically acquires data from one or many GNSS tracking stations, computes corrections and distributes them. Augmentation is essential to achieve high-precision GNSS positioning in post-mission or real-time (decimeter level or better). Augmentation services may be available in real-time or post-mission. Real-time appears to be the preferred approach of commercial service providers.*

A GNSS augmentation system usually includes the following infrastructure components: 1) a connected network of continuously operating GNSS tracking stations; 2) a central data acquisition and processing hub for GNSS correction generation and 3) communication channels for GNSS correction distribution (wired or wireless). GNSS augmentation systems can be ground-based (GBAS) or space-based (SBAS), depending on whether corrections are streamed over terrestrial or satellite communication channels.

The different components of a GNSS augmentation system may be owned and operated by a single entity or shared among collaborators. Collaboration may involve partners from both the private and public sectors. Business models often vary depending on the coverage area of the service, the application being served and the regulatory environments under which end-users operate. As GNSS tracking networks continue to be densified, new navigation satellite constellations emerge and internet access improves, means to better integrate the infrastructure components of GNSS augmentation systems should be considered. Improving collaboration could also help sustain continued and competitive service provision as the industry matures.

To help inform the federal GNSS community, this environmental scan will review the role Government plays in different business models used to deliver GNSS augmentation services. The major global and regional augmentation services available on all continents and used in Canada will be considered. A summary of investment in the infrastructure components will be provided for each augmentation system reviewed.” While not all augmentation systems are reviewed – not all responded to our requests for further information – this report will identify them, along with some background on each. Those organizations and individuals who did respond are identified in Appendix A. Again, as noted above, commercial suppliers were reluctant to provide anything but generalized information on costs.

3. Major GNSS Services Used in Canada

The basis for GNSS services is, obviously, the satellite systems. GNSS constellations are in Medium Earth Orbits (MEO) circling the Earth in about 12-hours. The satellites are positioned so that four to six are in view nearly 100 percent of the time from any point on Earth. The current GPS constellation includes 24 satellites and 6 active spares at 20,200 kilometers above the Earth. The current GLONASS constellation includes 24 satellites at 19,140 kilometers above the Earth. Other systems are in the process of being developed, including Europe’s Galileo which has four satellites and is expected to reach initial operational capacity in a few years. The fully deployed Galileo system is planned to have 27 operational satellites + 3 active spares) in orbits at 23,222 km altitude above the Earth. China has already launched an initial set of geostationary (GEO) satellites to reach initial operational capacity over Asia and is in the process of launching more to provide world-wide coverage. India and Japan also have regional navigation satellite systems (RNSSs) under development. This investment of billions of dollars was initially justified by the USA, Russia, China and India for military purposes. Both Japan and Europe have tended towards justification based more on commercial grounds. For all players justifications associated with commerce and efficiency in their economies are now also seen as important. The basic ground infrastructure that makes each navigation system “work” is a dedicated set of tracking and monitoring stations, which manage satellite orbit and timing information for each constellation.

At the global scale, high-precision GNSS, particularly for Earth Sciences applications, stem largely from activities of the International GNSS Service (IGS). The IGS was established in 1994 as the International GPS Service. The change in name reflects the gradual inclusion of constellations other than GPS. More than 200 organizations in 80 countries contribute daily to the IGS, which is dependent upon a cooperative global tracking network of over 350 GPS stations. Canada is a contributor. Data are collected continuously and archived at globally distributed Data Centers. Analysis Centers retrieve the data and produce the most accurate GNSS data products available anywhere, e.g., GPS orbits at the 3-5 cm level 3D-wrms, sub-centimeter station positions, velocities at the millimeter level and time transfer at the sub-nanosecond level.

Global deployment of a network of more than 350 GNSS tracking stations represents a total investment of at least $20 million assuming an average per-station cost of about $50,000 to $70,000. IGS provides user groups with easy access to an accurate International Terrestrial Reference Frame (ITRF), generated in partnership with the International Earth Rotation and Reference System (IERS) and other complementary geodetic techniques such as satellite laser ranging, and very long baseline interferometry. IGS products are also useful to determine the precise relation between the GPS/ GALILEO /GLONASS systems to facilitate multi-constellation inter-operability. IGS data and data products are made accessible to users reflecting the commitment of the organizations to an open data policy. The IGS serves many thousands of users and is viewed as a very successful scientific federation and a model for international co-operation. IGS is a recognized scientific service of the International Association of Geodesy (IAG).

At the other end of the spatial scale, regional requirements are met by initiatives such as the GNSS Service of the Greater Vancouver Regional District (GVRD). It is the only municipal system of its kind in Canada, although other cities are contemplating providing such a service. It operates a network of five active control points (ACP), hosts redundant servers for real-time correction generation and serves fifty usersincluding Public Works and Government Services Canada. The network was established to:

- Eventually replace the 13,000 integrated survey control monuments;
- Reduce overall survey and mapping costs;
- Provide consistency in the region;
- Be compatible with the provincial British Columbia active control system and the provincial geo-spatial reference;
- Allow for the rapid capture of all forms of spatial data (e.g. Socio-economic data) using GNSS; and
- Permit better emergency response services (e.g. fire, ambulance, police)

The system cost $2.4 million in 2002; however, the scope also included the establishment of a High Precision Network (HPN) consisting of 350 monuments and the survey of them – including integration into the existing dense survey control networks (10,000 plus monuments), publication of new horizontal and vertical datums and local geoid compatible with the 5 ACP network offering RTK, DGNSS and post-mission services. An annual operating budget of $350,000 is covered by levies to participating municipalities and to a lesser extent by external (public) user fees. The city relies on the Province and Federal Government to maintain the horizontal and vertical datums and the geoid model to which ACP and HPN coordinates and elevations are integrated. Given local crustal dynamics and Vancouver's location along the margin of the North-American tectonic plate, there is an increasing need to add velocity vectors to monument coordinates and elevations as well as a more precise local geoid to enhance GNSS-based local differential levelling (as part of 3-D positioning).

It is interesting to note the view that a municipality has on the respective roles of the different players. They believe that the federal government will (or should) lead in the development and maintenance of georeferencing standards and specifications in collaboration with the provincial and federal land surveyor associations, universities, and industry. The federal government is also expected to maintain and improve horizontal and vertical datums including the geoid. The provincial government will adopt and modify federally developed and maintained georeferencing standards, specifications and datums in collaboration with municipalities/regional governments, provincial land surveyor associations, universities and industry. The private sector will provide and promote their technological advances and products (e.g. software, hardware) and the government will eventually revise georeferencing standards and specifications based on the new technology. An industry representative noted that the varying approaches to GNSS in the provinces make any change difficult. Some can simply decide to change and do so, but New Brunswick was cited as the lone case where any change requires a change in legislation.

Table 1 provides a list of the major GNSS services used in Canada. For commercial reasons few of the commercial suppliers were willing to identify the relative importance of their major application markets and users. We have filled in the gaps in this Table using a combination of available promotional materials, the focus of print advertising we have seen, office location, statements on the company's web pages, and articles in the technical media (such as ***GPS World***, ***Inside GNSS***, ***Coordinates, LBX Journal, GIM International***, etc.).

To explain the mode of operation Chassagne (2012) compared Real Time Kinematic (RTK) (a differential augmentation approach) to Precise Point Positioning (PPP). He suggested that "the two techniques could be summarized in the following very simplistic manner (where "precise location" means the accurate location inferred from code and phase measurements, which is much more accurate than the location inferred from code measurements only):

RTK: "Tell me the precise location of your reference station and I will tell you the precise location of your mobile receiver."

PPP: "Tell me the precise location of the navigation satellites and I will tell you the precise location of your mobile receiver."

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Table 1: Major Navigation Satellite System Augmentation Suppliers/Services Used in Canada

Name	Coverage (Global, Continental, Regional, Local)	Mode of Operation (DGNSS, RTK, PPP)	Precision in X&Y (and Vertical)	Major Sectors Served	Operational or R&D Gov't or industry	URL
IGS	Global	PPP	Not App	Earth science researchers	R&D and O	http://igscb.jpl.nasa.gov/overview/viewindex.html
Trimble RTX	Global	PPP/RTK Hybrid	3.8 cm	Agriculture, GIS/Mapping, Exploration, Airborne Survey,	O/Industry	http://www.trimble.com/agriculture/CorrectionServices/centerPointRTX-cell.aspx
John Deere NavCom	Global	PPP	5 cm	Land survey, agriculture, machine guidance	O/Industry	https://www.navcomtech.com/navcom_en_US/support/faqs/starfire/starfire.page
Hexagon Veripos	Global	PPP	5-10 cm	Primarily marine off-shore services & land navigation	O/Industry	http://www.veripos.com/
Trimble Omnistar	Global	PPP	5 cm	Agriculture, GIS/Mapping, Exploration, Airborne Survey, UAVs, Scientific Research;	O/Industry	http://www.omnistar.com/AboutUs/CompanyInformation.aspx
Fugro Seastar	Global	PPP	<1m to 10 cm	Marine – off-shore survey	O/Industry	http://www.fugroseastar.com/
WAAS	Continental	DGNSS	Better than 1 m & (l.5 m)	Aviation	O/Govt	http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/faq/waas/
CCG/ DGPS	Coastal	DGNSS	1-3 meters	Marine	O/Govt	http://www.navcen.uscg.gov/index.php?pageName=dgpsMain http://www.ccg-gcc.gc.ca/CCG-DGPS/Marine-Differential-Global-Positioning-System
Plate Boundary Observatory (PBO)	Regional	RTK	5-10mm	Science – plate movement	R&D/Govt	http://www.earthscope.org/science/observatories/pbo/
Leica SmartNet	Regional	RTK	1-2 cm	Land survey, machine guidance	O/Industry	https://www.smartnetna.com/coverage_network.cfm and http://www.leica-geosystems.com/en/SmartNet_95099.htm
CanNet	Regional	RTK	1 cm	Land survey, agriculture, GIS, machine control	O/Industry	http://www.can-net.ca/ and http://www.cansel.ca/en/
TopCon TopNet	Regional	RTK	1-2cm	Land survey, machine guidance, agriculture	O/Industry	http://www.topnetlive.com/
Metro Vancouver	Local	RTK	4 cm (6cm)	Land survey, mapping	O/Govt (Local)	http://www.metrovancouver.org/gnss

4. Augmentation Systems Used in Major Economic Sectors

4.1. Introduction

Four major sectors were targeted by the client: Transport, Natural Resources, Public Safety and Science. Originally it was hoped that one could obtain detailed information on the level of investment in three components of GNSS augmentation – acquisition, processing and dissemination for a typical augmentation system servicing each one of the sectors. However, the importance of the private sector, along with the competitive environment and how stations are funded, made collection of precise information impossible in but a few cases. First, companies did not want to share what they regard as commercially sensitive cost information, especially on processing and internal costs. Second, while all suppliers are quite willing to share information on the number of stations, they would not provide details on how much it cost to install and operate them. Third, to calculate operating costs is difficult: many stations are located at the premises of users – for example a land surveying company. The surveying firm may get a discount on use of the services for using their location or for maintaining the equipment. Fourth, commercial suppliers will not usually provide details on the costs of their underlying infrastructure. Lastly there appears to be some confusion over terminology. Different technologies and different types of station seem to be called by the same names by different groups with whom we have been in contact. Moreover, some costs provided include some items while others do not, leading to lack of direct comparability. For these reasons calculating the true cost of locating and maintaining any particular station or set of stations is difficult.

In order to move forward and provide order of magnitude cost estimates for a typical augmentation system, a number of assumptions were made about costs to install a control station monument (of different grades, e.g., metal pipe on building to concrete pillar cemented in bedrock) and deploy a GNSS receiver and related equipment at a continuously operating reference station (CORS) that consists of a control station (physical monument) and GNSS receiver and related equipment. Other elements of the cost are the communication links and servers needed to actually run the network. We have been greatly aided in this task by the willingness of commercial suppliers to share their general cost estimates as well as detailed information from the PBO activity, from the Canadian Geodetic Survey, the Canadian Coast Guard, and the Government of Australia. However, commercial suppliers are unwilling to provide details on costs and investments in the very competitive space in which they work.

The PBO activity has established real costs for a range reference stations in widely different locations – from urban and easily accessible to those in remote inaccessible locations in Alaska. Table 2 provides the costing formula we have used based on the basic hardware. Table 3 was provided by Australia. Comparing the two tables, one can see that the costs for the basic hardware are the same. The cost estimate in Table 3 would seem to include the broadest range of costs that might be encountered. Indeed, it includes several line items that would not immediately come to mind – such as the Heritage clearance – an assessment as to whether or not the site selected contains any “Aboriginal site, object or remains.” These costs are far higher than those cited by commercial suppliers of GNSS augmented services. This is in part because of how the commercial entities arrange to use a client’s premises as the site and, by so doing, avoid a number of costs, including the heritage clearance and lease, construction, equipment huts, and the like. For commercial RTK service providers in urban areas, the following items can be removed or greatly reduced from Table 3: construction (a few $K), equipment huts, weather station (as they tend not to include such luxury features), power, batteries, freight and travel (local delivery), and leasing; so the urban RTK reference station installation cost can be as low as ~$30K while more remote sites can be estimated to start at $45K and go much higher depending on additional costs such as batteries, shipping and transport, access, solar panels, etc. as outlined in Table 3.

Table 2: Determining Costs for Continuously Operating Reference Stations		
	Capital Cost (GNSS Receiver and GNSS antenna, cables, solar panels)	**Annual Operating Cost**
Reference Station – accessible	$30,000	$5,000
Reference Station – inaccessible	$45,000 and up (see explanatory text)	>$12,000

Item	Cost
Construction	$50,000
Reference mark including plate, collar, etc.	$2,000
Equipment Huts	$7,000
Solar Panels	$3,000
VSAT Communications	$6,000
GNSS Receiver	$15,000
GNSS Antenna	$5,000
Cables	$1,500
Automatic Weather Station	$15,000
Power Distribution Supply	$5,000
Batteries	$7,500
Freight	$15,000
Travel and Reimbursable	$10,000
Heritage clearance, parcel lease, etc.	$10,000
Cost per station	**$152,000**

Table 3: Estimated Cost (in Australian $) of Establishing a New GNSS CORS site (Lawson, 2014)

Costs are provided in as much detail as possible for each sector. Given that RTK and PPP systems may serve users in different sectors, a separate Sub-section (4.8.) at the end of this Section estimates the total investment and operating costs for those systems operating in Canada.

Augmentation services were profiled in each of the required four sectors: Transport, Natural Resources, Public Safety, Emergency Management, and Science, with estimates of investment and maintenance costs. We have covered more services but estimates are, at best, approximate. While companies who file statements with the US Securities and Exchange Commission do show income, it is not provided at the level that allows one to extract the costs and income associated with the augmented GNSS portion. Depending on the service, estimating the number of users may not be possible. Also, in some cases where the number of users has been estimated (see the discussion of Hungary, for example in Section 5.3.3.), the numbers do not seem believable. We do apply the ACIL Australian study where appropriate to try to determine the potential impact of augmented GNSS in Canadian terms.

The balance of this section details how a number of GNSS augmentation systems have been used in each of the four major economic sectors called for, along with additional Sub-sections on Land Survey and on what we call Emerging Sectors. In discussions with several suppliers, the land survey sector was said to consume as much as 50% of their augmented GNSS services. While the statement of work had included land surveys under Natural Resources, recognizing its importance led to its treatment in a separate Sub-section. Similarly, while it was expected that the report would only cover a limited selection of user applications and systems – one of each in each sector, we have tried to provide a broader and more comprehensive view of a more complete range of applications and service providers under each topic. By so doing we provide a richer context in which to understand GNSS augmentation services and the role of government. An important part of this context that has become evident in this study is the competitive environment in which both service and technology providers and the Government of Canada must operate. There has also been some attention paid to the use of GNSS that is not augmented as a point of departure. Following the discussion of the major and emerging sectors, Section 4.8 summarizes the investments and operating costs of the major GNSS augmentation activities in Canada. The final Sub-section provides some statements on the potential roles government departments and agencies, not normally involved in GNSS augmentation, may play in the future.

4.2. Transport

4.2.1. Introduction

Perhaps nowhere is the connection between GNSS technology as a whole and global user needs more mission critical and visible than in the transportation sector. The transportation sector was one of the first large scale civilian sectors to significantly adopt GNSS technologies on a large scale, and even today it is estimated that one half of all revenues generated by all satellite navigation programs come from the transport sector. While augmented GNSS services are not yet widely used in some areas (such as road transport) they are critical in aviation and are of growing importance in marine and rail transport (European GNSS Agency, 2014). GNSS is especially important for Canada’s transportation sector due to its large landmass and relatively low population density. Indeed, many see transportation as an essential backbone to the Canadian economy and quality of life, as well as an important part of our history.

The use of augmented GNSS varies greatly between the four modes of transport: road, rail, air and maritime. The technology applied, level of investment, role of government and applications vary significantly from one mode to the next. To avoid confusion this Sub-Section is organized by mode of transport. GNSS technologies, applications and role of government for each mode are then discussed in separate Sub-sections. It should be noted that GNSS augmentation capabilities are not essential for all transport applications. For completeness and to provide context the use of GNSS that is not augmented is provided as a starting point. That said, given the number of applications and users that do rely on additional accuracy, and the fact that reliability provided by augmentation systems continues to grow, additional growth in use can be expected.

4.2.2. Road

GNSS applications supporting commercial as well as personal road navigation have been growing globally in the last decade. While most of these applications do not require augmented GNSS as defined in this report, they use GNSS augmented by (mostly) road map matching algorithms.

In the USA the transport departments in many states operate CORS stations. For example the state of Iowa and surrounding states have a network of stations which they own and/or maintain (See Iowa, Accessed 3/2/2015). Gakstatter (2014) has identified 31 states that operate or provide access to RTK sites. A number of these are actually PBO sites. While RTK stations are operated or owned by Departments of Transport, the primary application is, in fact, surveying associated with road construction and maintenance. One commercial supplier noted that while the state of Iowa gives away its data, other users actually buy the commercial service rather than obtain free data. This supplier believes that state agencies will, over time, only supply data internally to the state government, if at all. In Canada the situation is somewhat different. While Nova Scotia is deploying a province-wide RTK system with 20 stations (planned to grow to 40) operated in partnership with the private sector, both Quebec (with 17) and British Columbia (with 7) have their own RTK stations in selected cities and regional municipalities (Donahue et al, 2013).

In the future, it is likely that augmented GNSS will be used rather than just GNSS to improve positioning accuracy in systems requiring tighter integration between driver navigation and vehicle safety information. In any case, the wide availability of GNSS devices may well lead to an increased interest in precision, as it has in other sectors and other technologies. As has been reported elsewhere, "accuracy is addictive"(Economist Technology Quarterly, 2002). This interest in increased precision will become more prevalent as driver-assist and autonomous or "driverless" vehicles move from research to the market place and user fees are applied for specific roads based on a transponder's location. GNSS applications generally requiring lower accuracy in road transport include:

- Personal Navigation Devices (PNDs) for navigation support to all types of road vehicles;
- In-Vehicle Systems (IVS), a device dedicated for personal navigation;
- Systems for Pay-Per-Use-Insurance (PPUI);
- Advanced Driver Assistance Systems (ADAS). General Motors provides the commercial system "OnStar" which in North America provides subscription-based communications, in-vehicle security, hands free calling, and navigation support. An additional example is the recent European initiative eCall, which is a device to be installed into all new cars sold in Europe that automatically calls the 112 emergency number in the case of an accident or other emergency. The eCall device will be mandatory on all new car models that are type approved in Europe as of 2018 (European GNSS Agency, 2014);
- Digital Tachograph (DT). EU policy has made DTs mandatory for vehicles with a mass of more than 3.5 tons in goods transport and those carrying more than 9 persons in passenger transport, in order to enforce rules on driving times and rest periods, guaranteeing fair competition and road safety. The new regulation introduces the use of GNSS positioning in future DTs. GNSS technology will help automate operations so far performed manually to record the position of the vehicle at determined points, with estimated cost-saving of €350 million per year for the sector. The presence of GNSS in DTs will also foster the use of the satellite-based positioning to guarantee the origin and integrity of the DT records and will open up further possibilities for the introduction of a standardized interface to support Intelligent Transport Systems (ITS) applications.

The first expected routine use of augmented GNSS (i.e. not augmented by road maps) in road transport will be systems that support Road User Charging (RUC). These are expected to see significant growth over the next decade, from highway tolls, to the general use of inner city roads during peak hours. Augmented GNSS will play a special role in congested cities and toll roads to appropriately charge drivers using more expensive "fast lanes," or where one must be able to reliably determine if a vehicle is on toll highway, or a nearby road. As noted above, another major anticipated use some time in the future will be autonomous or driverless cars. More immediately one might anticipate the use of augmented GNSS in what we call assisted driving – to help drivers stay in the correct lane for example.

4.2.3. Rail

Railway lines are somewhat problematic for GNSS because of high safety requirements that are comparable to aviation, combined with a challenging environment with the presence of tunnels, covered stations, etc. where the satellite and augmented signals are not available. Integrated solutions combining GNSS with other technologies such as inertial navigation systems and traditional odometers can provide a good level of coverage in these challenging environments. It is in this area where augmented GNSS becomes especially useful. This is particularly the case for applications resistant to small periods of reduced accuracy. In general, the main advantage of the GNSS-based solution is that it allows for a remarkable increase in safety at a lower cost than other solutions (European GNSS Agency, 2014).

Traditionally, track-based systems have detected the presence of a train and relayed this information back to a signal and control system. This would then be sent back to the driver in the form of line-side signals, providing the train with the authority to pass a particular point along the track. In the future, a train is expected to detect its own position, through different technologies such as RFID and GNSS. This position will then be reported to the control and movement authority and displayed 'in-cab', removing the need for costly lineside signaling infrastructure – and reducing the potential for tampering. As a result, GNSS will see increased use in safety-critical devices and offer additional support to non-safety applications (asset management and passenger information). In Europe, and in some parts of the rest of the world, the signal system will gradually migrate to such a system. GNSS will support this program by providing an additional source of positioning information, especially in the evolution of the signal system. In some cases (such in the USA) it is expected that GNSS will form the core of the signal system, whereas in others it will more likely be a fallback capability (European GNSS Agency 2013). Again, while augmented systems may not be required for many applications today, one can envision situations in rail transport where the precision offered may be beneficial.

4.2.4. Aviation

There are GNSS-certified devices for commercial, regional, general & business aviation, and uncertified devices aiding pilots flying under Visual Flight Rules (VFR). Navigation systems in aviation demand the highest robustness and integrity. They support continuous operations in aircraft and aerodromes of varying infrastructure complexity. GNSS applications in aviation vary greatly depending on the accuracy and integrity of the position needed. Operations relying on GNSS are subject to certification (Instrument Flight Rules), otherwise GNSS can be used as an additional aid to the pilot without requiring regulatory approval (VFR).

Aviation, already a major user of satellite technology, sees its dependency on such technology growing. Current GNSS systems alone cannot support all air navigation requirements due to several factors: integrity is not guaranteed; all satellites are not monitored at all times; time-to-alarm is from minutes to hours; there is no indication of quality of service, and finally, the accuracy is not sufficient (European GNSS Agency, 2013).

Around the world, GNSS enabled augmentation systems (such as the European EGNOS and the North American WAAS) have been designed and implemented to support airspace users to improve today's non precision approach operations, as recommended by International Civil Aviation Organization (ICAO). The introduction of such systems for aviation is part of a wider strategy for new navigation capabilities, and is a priority for ICAO. Improved real-time accuracies in the vertical are especially important. Those being delivered today can be better than 1 meter in the horizontal, and better than 1.5 meters in the vertical. (See Table 1 in Section 3.) In a previous study it was noted that PPP may be especially useful in serving the far North and the military, in that it offers the potential for even greater real-time accuracies without the necessary ground systems (Ryerson et al, 2009).

GNSS is essential for the introduction of Performance-Based Navigation (PBN) in line with ICAO standards that place requirements on the quality and accuracy of aircraft navigation along predefined routes, on an instrument approach procedure or in designated airspace. It envisions a transition from traditional ground-based navigation towards space-based navigation.

GNSS helps to increase safety, reduce congestion, save fuel, protect the environment, reduce infrastructure operating costs, and maintain reliable all weather operations, even at the most challenging airports. In the former case (commercial) GNSS use will increase as more flight procedures are designed to take advantage of PBN. For example, Localiser Performance with Vertical (LPV) guidance is an instrument approach procedure that provides lateral and vertical guidance based on GPS augmented by SBAS (EGNOS/WAAS) down to 250 ft. minima. LPV systems are already being rolled out primarily in Europe and the USA, increasing safety and business continuity at airports. New GNSS constellations are expected to be available in the next few years providing multi-frequency and multi-constellation navigation capabilities, which may improve the performance of existing PBN applications. It is expected to be a key enabler for Ground Based Augmentation Systems (GBAS), resulting in lower minima to CAT II or CAT III standards, demanded by some commercial operators. Today, 163 LPVs are operational in

106 airports, and more than 500 runways plan to use EGNOS-enabled approaches by 2018. In addition, EGNOS-enabled devices are expected to dominate the European market, especially the regional, business and general aviation segments – growing from some 20% in 2012 to 40% in 2018.

In North America, the Wide Area Augmentation System (WAAS) was implemented mainly for the civil aviation community. WAAS was declared operational in late 2003 and continues to develop as usage grows. It currently supports thousands of aircraft instrument approaches in more than one thousand airports in the USA and Canada. (Federal Aviation Administration, Accessed 2/18/15). The total development cost of the program as of 2000 was almost $4B. (House of Representatives Accessed 2/20/15). The cost to provide the WAAS signal, serving all 5,400 public airports, is now said to be just under US$50 million per year in Wikipedia. Official reports put the operating costs (primarily for communications at $65 million in 1997 (General Accounting Office, 1997). In comparison, the current ground based systems such as the Instrument Landing System (ILS), installed at only 600 airports, cost US$82 million in annual maintenance. Without ground navigation hardware to purchase, the total cost of publishing a runway's WAAS approach is approximately US$50,000; compared to the $1,000,000 to $1,500,000 cost to install an ILS radio system (Aircraft Owners and Pilots Association, Accessed 2/20/15).

While commercial reliance on GNSS is growing, it is the smaller plane and general aviation market which is the largest GNSS aviation sub-segment, and has more aircraft and pilots than the business, regional, and commercial segments combined. Sales in general aviation are dominated by VFR users that replace their devices more frequently to have the latest functionalities on board. The cost of equipping IFR devices is much higher, therefore commercial, regional, and business aviation retrofit only once during the aircraft operational life (around 30 years). That said, commercial aviation GNSS shipments are predicted to increase as GNSS capabilities are enhanced in response to regulatory changes, and the need for commercial operators to support routes to an increasing number of destinations. As a result, commercial aviation GNSS manufacturers are expected to capture approximately 30% of the Aviation market revenue by 2022 (European GNSS Agency, 2013).

In addition, in the frame of the "European GNSS Evolution Program" (EGEP), ESA is preparing the next version of EGNOS, which will require further, significant government investments. This project is currently in its definition phase, but in parallel, test beds have been developed in the frame of EGEP. Among them, High Integrity System Test Bed (HISTB) is designed to assess future EGNOS services for aeronautical users (Delfour, et al, 2014).

4.2.5. Marine Shipping

Global maritime traffic is increasing and Canadian ports and inland waterways are becoming more congested. This growth requires new solutions to improve efficiency, safety and minimize the impact of maritime traffic on the environment. Accurate and reliable positioning are key elements for streamlining port operations, improving safety and protecting the marine environments. New satellite based systems that can reduce response times in case of an emergency are also being deployed.

GNSS devices support general navigation, as well as provide inputs to the Automatic Identification System (AIS), the Long Range Identification and Tracking (LRIT) System, port operations (including portable pilot units), dredging, and search & rescue beacons. Normally, AIS is limited to transmitting information to coastal receivers and then to Vessel Traffic Monitoring and Information Systems (VTMIS) operated by Coast Guards. Interestingly, a Canadian company exactEarth has deployed a constellation of satellites which detect these signals in mid ocean, and generate a comprehensive global near-real-time plot of shipping.

In Europe, GNSS augmentation through the regional EGNOS system is delivering a variety of new capabilities in support of maritime operations. Accurate positioning enhances the precision of Vessel Traffic Monitoring and Information Systems (VTMIS), which manage vessel movements and increase both efficiency and safety. Many ports are congested and require systems to ensure efficient operations whilst guaranteeing safety. Furthermore, the increase in the size of cargo ships has led to the need for extremely accurate maneuvering. One solution is portable Precise Point Positioning (PPP) units deployed with Pilots (the local master mariners embarked in congested waters and ports to navigate visiting merchant ships) that provide increased confidence and accuracy in the vessel's positioning while they are being navigated through very restricted waters such as canals and port approaches, where GNSS levels of accuracy are not sufficient. As an experienced ship commander, Mr. Bancroft has stated that "*the last hundred meters of the approach of a ship to the jetty is the most critical phase where poor decisions lead to costly damage at the jetty*", and that he "*fully expects to see in my lifetime that ships will be docked more safely with augmented GNSS tools than human judgment alone."*

Many systems installed on leisure craft already integrate PPP corrections. The resulting precise positioning, especially in tight waters, makes navigation easier and safer. On rivers and other inland waterways, satellite PPP already complements existing ground-based systems (European GNSS Agency, Accessed 02/10/15).

In North America, the US Coast Guard and the Canadian Coast Guard both operate Differential GPS (DGPS) services which broadcast GPS correction signals on marine radio-beacon frequencies to improve the accuracy and integrity to GPS-derived positions. Users can expect better than 10-meter accuracy throughout all established coverage areas, but typically, the uncertainty of a DGPS position is 1 to 3 meters, greatly enhancing harbor entrance and approach navigation. In addition, this maritime service provides 10-meter (2 dRMS) navigation accuracy and integrity alarms for GPS and DGPS out-of-tolerance conditions within ten seconds of detection (US Coast Guard, Accessed 2/18/15).

4.2.6. Future Developments

Increasingly, in transportation, we are seeing the development of automated vehicles emerging for air, land and marine applications. The use of Unmanned Aerial Vehicles (UAVs) as a commercial delivery system in the urban environment is being tested by Amazon, including in Vancouver. Apple, Google and several car manufacturers are investing in the development of driverless cars and trucks. Unmanned commercial cargo ships have been discussed. Closer to shore, input from the Canadian Coast Guard GNSS Program authority included the following unsolicited comment, "The improved accuracy offered by DGPS is taking on a greater significance in the 21st century. This is because the use of highly accurate positional information is central to the functioning of navigational aids like Electronic Chart Display and Information Systems (ECDIS) and Automatic (ship) Identification System (AIS)" (Personal Communication, John Festarini, 02/18/15).

As new technologies are developed and prototypes implemented, policy makers and regulators are increasingly left scrambling as they attempt to predict user demand for augmented GNSS services over the next decade. Will UAVs be approved for use in delivery? What are the insurance implications for autonomous vehicles? Will earthquake prediction become a reality – and how might that affect transportation safety? However, regardless of how these questions are answered, one thing is clear: the need will grow for trusted and authoritative augmentation systems delivering increasing horizontal and vertical resolutions with high reliability. This in turn will drive the need to monitor the integrity of such systems, a role that is typically seen to be the role of national governments.

4.3. Natural Resources

4.3.1. Introduction

For this study, natural resources include agriculture, mineral and oil exploration and development, environmental studies, and forestry. Almost every augmentation system, whether RTK-based, or PPP[2], plays in at least some way to one or more of these areas, although some would appear to be more focused on one specific activity. For example, one would expect that John Deere's NavCom Starfire system would be more focused on agriculture given John Deere's position as a major agricultural machinery manufacturer. At the same time one would expect Fugro's SeaStar to be associated with oil-related services and transportation on the oceans. Similarly, CanNet is within a company serving the land surveying community. While the John Deere Starfire system does serve the agricultural market, it also serves the land surveying profession.[3] According to a 2011 article in Navipedia, the major suppliers in agriculture are John Deere (NavCom Starfire), TopCon (TopNet), Hexagon (Leica), and Trimble (Omnistar). CanNet does see the land survey market as its primary market, but growth, and how it approaches service delivery, has come in serving the demands of the agricultural market.

The one observation we can make about commercial services and their application is that while most tend to have a specific focus, all of them will serve whoever comes to them with a request for location information. This is particularly so where the service is based on an RTK network. Once the network is in place, adding more users does not add significant cost. The same might be said for PPP, although some PPP service providers have tended to specialize – for example in maritime applications.

In addition to operational applications serving the resource sector, there are science and research implications – the precision provided by precise point positioning, for example, allows one to return to exactly the same position for field work involving sample plots – or to take samples around a particular rock formation for diamond exploration in the high Arctic. Augmented GNSS is used for plot work in Agriculture and Agri-Food Canada Research as well as by researchers in forestry who wish to return to the same exact tree.

The following subsections contain a sample of augmentation systems used in the natural resources sector, including their technical description, funding and investment, role of government, and applications, with special reference to their importance in Canada.

4.3.2. Technical Description

The precision and accuracy one finds cited associated with natural resources applications using PPP technology is similar across the several vendors that offer the service. For example the NavCom Starfire system offers "better than 5cm" from 72^{o} N to 72^{o} S using 40 reference stations." The service is offered worldwide, but is not available in the far north and far south due to the limited coverage of the communication beams over which the geostationary satellites broadcast. The Starfire system has redundant computing centres, advertises an "up-time" of 99.999% and offers corrections to GPS and GLONASS satellites. The system can also use both satellite communications and Internet delivery and has minimal latency.

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[2] The reader not familiar with the field is reminded that PPP as used here is short form for precise point positioning – not public private partnership.

[3] See the web page that showcases cadastral applications at https://www.navcomtech.com/navcom_en_US/products/equipment/cadastral_and_boundary/cadastral_and_boundary.page

Latency is an important issue in PPP. Latency is the delay in obtaining the first position within the accuracy specifications. With a PPP solution, at receiver startup following the loss of lock to most satellites, one is usually faced with the solution having to re-converge. This could take a few tens of minutes. NavCom solves this problem with an approach that they call “Rapid Recovery.” In essence, if the receiver loses the lock on a satellite (a vehicle going under a bridge, for example) or if the receiver is shut down (overnight on farm equipment) the system can start up again and have a position within two seconds (NavCom, Accessed 2/4/15). Trimble’s OmniStar offers similar accuracies and services, with the best latency offered seeming to be 60 seconds, according to their web page. The Trimble Omnistar web page shows a variety of geographic areas ranging from the entire planet to most of the more densely settled (or farmed) areas of the world, depending on the specific service being used (Trimble, Accessed 2/4/15).

A common feature of the two systems profiled under PPP for natural resources is that not all services are offered in the high Arctic. While PPP works everywhere, and the corrections are valid everywhere, the communication satellites that are used to supply users with PPP corrections tend to be geostationary, and therefore cannot transmit signals effectively to Polar regions. Looking at the publicity and marketing material available on the web pages cited above, it would not be obvious that NavCom is a subsidiary of one of the most advanced farm equipment suppliers in the world. The lead application for their solution, given what appears on their web site, would appear to be cadastral mapping. On the other hand, Trimble, long associated with survey equipment, has but one applications brochure on its web site – and that is on agriculture applications. This apparent dichotomy is yet another measure of the complexity and competitiveness of the market.

RTK augmentation systems also serve the natural resource sector where there are reference networks of tracking stations in place. RTK accuracies are typically 1-2 cm horizontal and 3-5 cm in height. Redundancy has now been built into most RTK services to accommodate the agricultural market which often operates equipment 24/7 for weeks at a time: as was stated in an interview by CanNet “*we cannot afford to go down for even a minute*.” In Canada RTK networks are deployed mainly in the Quebec City-Windsor corridor, the prairies, the lower mainland of British Columbia, the oil sands region of Alberta and parts of the Maritimes. Different suppliers tend to focus on different regions and somewhat different applications.

TopCon’s TopNet focuses on southern Ontario, near northern Ontario (Sudbury/North Bay), southern Quebec, New Brunswick and Nova Scotia. TopNet has a dense network in California, the Eastern Seaboard of the USA, Georgia, and Mississippi. Topnet also has relatively dense networks in a number of European countries including the UK, Norway, Germany, and others. It also services several areas in Australia, and limited areas of South America, Mexico, and the Caribbean. The advertised accuracies for TopNet are 1-2 cm in x and y, and 2-3 cm in height (TopNet, Accessed 2/4/15).

Leica’s SmartNet RTK service (owned by Hexagon) has 100 reference stations in Canada and 550 in the USA. They work in parts of five provinces (Ontario, Quebec, Prince Edward Island, Nova Scotia and New Brunswick) with dealers working on their behalf in the four western provinces (Leica Smartnet, accessed 2/4/15). Leica is also active throughout Europe, in Brazil, parts of Africa and Asia. The importance of their international business can be seen from their web sites being available in over 15 languages. SmartNet’s reported accuracies are similar to those reported by TopNet. Leica is also doing some DGPS work.

CanNet’s RTK service has over 300 reference stations in the settled areas of the country. Included in their 300 stations are 20 they operate for the Government of Nova Scotia. Associated with a company that sells and services equipment, they have 18 service technicians across the country who can respond immediately to issues with any one station. In response to the increasing capabilities of the technology, CanNet has found that the coverage for any given station is increasing. As a result, every year they routinely move a few stations to maximize coverage and minimize overlap.

4.3.3. Funding and Investment

One of the companies interviewed stated that a reference station typically listed for $24,000 for the hardware, but noted that few actually pay that price…he stated that prices could be as low at $15,000. The Australian estimates in Table 3 put the costs somewhat higher, a difference that may well be a function of shipping and exchange rates. Another company said that the stations cost $20,000. What often happens is that a dealer or user will provide in-kind support. For example, a dealer or user will house and maintain the station in return for a lower price for the service. As noted above in Table 3, there are many other costs that may be associated with the establishment of a station, depending upon its location, remoteness, and business arrangements.

One individual working for one of the larger companies stated that the control stations cost up to $70,000 each. The same individual said that the software to run a set of four reference stations originally cost as much as $50,000, and that annual maintenance and upkeep for these was $6000 (We assume this to be a reasonable estimate given the average PBO annual maintenance fees of $5,800 for a remote station). In addition, most commercial services seem to maintain a number of servers located in different regions to provide redundancy – a key selling point to those requiring real-time service. One $70,000 server can support 400 connections to reference stations or rovers. We were also told that each reference station requires $3000 per year for software licenses. If these numbers are correct, and without taking exchange rates into consideration, this yields a cost of as much as $9000 per year for maintenance and software. Thus for every 100 stations the IT and processing costs per year approaches $300,000 and maintenance is $600,000. (This is, it should be noted, similar to what PBO calculated (See Section 4.5.3. – $5,800 US$ per station.) It has been stated that TopCon and Leica have, between them, over 225 reference stations in Canada. CanNet has another 300 stations.

Together then, just these three companies have a total investment of over $12 million for the stations, an estimated $1 to $2 million in servers and an annual maintenance budget of several million dollars. Assuming equipment replacement every five years, then the annual cost of maintenance and depreciation (assuming zero interest) totals well over $5 million per year for just these three companies.

4.3.4. Role of Government

As with other Economic Sectors, Government support includes provision of the satellites. Government support has been acknowledged as limited but important by the commercial providers with whom we interacted. Some private RTK services, for example, include streams of tracking data from NRCan tracking stations in their network solutions. We were also told that governments provide other support such as control coordinates for some stations. Governments can also be clients – for both hardware and services. In effect, one of the contributions by government is the confirmation of the legitimacy of the services being provided by industry. This important government role was underlined by several of those we interviewed.

One individual working in GNSS augmentation in the private sector, trained in geomatics and geodesy in a major Canadian university, said "*People really don't know how GPS works – it is magic to most – even the users*." Having a reputable Government agency confirming the validity of what is being done is, it would appear, important. The fact that geodetic expertise found in the public service not only understands the technology, but is developing the science for use in Canada and internationally, is also important in securing Canada's place at the international table. This capability is significant in a country that does not own or operate navigation satellite constellations as do other major provider countries or unions (e.g. US, Russia, China, India and the EU). The cost of the GPS satellites launched by the USA up to 1995 was estimated to be $5 billion in 1995 $. (The total cost to the military was said to be much more than that when one includes the costs of weapons systems and the like.) Canada has 6% of the land area in the world, benefits greatly from the GNSS system, while paying just a small fraction of their cost. Indeed, of the eight largest political jurisdictions in the world, five of them have their own GNSS satellites. Only Canada, Brazil and Australia do not. Some have said that Canada gets a “free ride” on the US GPS system.

4.3.5. Applications

The application of GNSS in natural resources is highly varied, significant and growing. In an editorial in ***Geospatial World*** Ray O’Connor (2015) CEO of TopCon stated that *“there is an old but very accurate saying, “You can’t manage what you can’t measure.” Today, in all forms of geopositioning, that adage is more appropriately edited to say, “You can’t manage in real time what you can’t measure in real time.” This is a major change across every industry that our technology touches. We are going from the inefficiencies of post-processing to the agility of real-time data.”* He goes on to say that more accurate real-time positioning will be critical in meeting two major needs faced by the world today – improved agricultural productivity and replacing and updating the world’s decaying infrastructure. These two challenges form the basis of this section.

Here we will discuss three areas: agriculture; machine control associated with mining and construction; and (briefly) field work associated with both exploration and environmental studies.

In precision agriculture, GNSS augmentation services are being widely used. As early as 2006 (Buick, 2006) Trimble reported that 80-100 million acres of crop in the USA were being farmed by RTK-controlled equipment. This provides an indication of the market and the degree to which Trimble on one hand, and John Deere on the other, have control of a large market. The competition over this large and growing market explains the reluctance showed by companies involved to share information on markets, including the user base and costs. Even taking this eight year old figure, this acreage represents almost 33 % of the harvested cropland in the USA that year. By making a few rough estimates based on cropland area, the number of larger farms likely to use GPS (we assume farms over 500 acres), one can conclude that the number of farmers using such devices in 2006 was a minimum of between 50,000 and 100,000 – and perhaps many more. An even higher estimate was provided by the United Nations (2004) which suggested that there were one million users in agriculture in the USA – in 2004 there were only 2.2 million farms in the USA. Regardless of what the number of users is, that the number is high is corroborated by the European organization representing 4500 manufacturers selling farm equipment. They estimate that “70 to 80% of new farm equipment sold today has some form of Precision Farming component inside” (CEMA Accessed 2/4/15).

The agricultural uses of GNSS augmentation services are straightforward: they are used for tractor guidance and automated control of ploughing, seeding and spraying (herbicides, pesticides, and fertilizer), field crop planting, spraying of herbicides and pesticides, tillage, yield mapping, and soil assessment. The EU conducted a study that suggested that GNSS could additionally be used in “mechanical weeding, cow fertility detection, virtual fencing, land parcel identification and geo-traceability, post-harvest pick-up, supervised tracking of livestock, field boundary mapping and updating and field measurements” (European Union accessed 2/5/15). It is also used in orchard and vineyard management and harvest planning. These uses are, however, generally restricted to the large fields and/or expensive crops of the USA, Canada, Western Europe and Australia, with some use in Brazil and Argentina. Invoking concerns about privacy and who owns what information about a specific farmer’s crops and practices, there has been a great deal of discussion on the amount of knowledge that the suppliers of services obtain about individual farmers and their land. Even so, John Deere has stated that their clients number in the “Tens of thousands.” The global market size for precision farming has been estimated to grow to over $6.34 billion by 2022 at an estimated compound annual growth rate of 13.09% from 2015 to 2022 (Navipedia, 2011).

This growth includes the cost of systems purchased by the farmer, not just the GNSS augmentation services.

The economic impact of GNSS augmentation services in Canada have not yet been studied in any detail and such an analysis is not required for this study. However, while conducting this scan, we can draw some interesting conclusions on the benefits of GNSS augmentation services to Canada. Australia has carried out a detailed economic study (ACIL Allen, 2013). They estimate that the economic impact of GNSS on grain farming in 2012 was from a low of $279M to a high of $434M. These benefits could more than double by 2020 if technology is adopted as expected. The impact on dairy and beef farming was similarly estimated to be from $18M to $29M in 2012, dramatically increasing to from $105M to $791M in 2020. Other economic studies, including preliminary results from the HAL study just being completed for the Government of Canada, suggest that benefits achieved in the geospatial realm in Australia are similar to those achieved in Canada, depending on the relative size of the sector. Australia's grain acreage at 18M hectares is approximately 10% larger than Canada's 16M hectares (Australian Bureau of Statistics, 2014; Statistics Canada, 2013). If the technology uptake and benefits are indeed the same (and we expect that market penetration is at least as great in Canada) this leads to an impact in Canada for grain farmers from about $250M to $390M in 2013. Using the same relative statistics for dairy and beef farming leads to similar benefits in the tens of millions of dollars, growing to hundreds of millions by 2020.

Forestry is often seen as a similar activity to agriculture, but with a longer "crop" growth cycle measured in decades rather than months. The comparison falls down in terms of the applicability of precise location information. Forestry does not require the same level of machine guidance to apply chemicals, or prepare for planting. The forest industry does use GNSS augmentation services for building access roads and to target specific trees for selective harvest. However, a number of researchers and forestry professionals have found that using GNSS services can be difficult under a dense forest canopy or where there is severe topography. Use can also be complicated through the lack of cell phone coverage. One major potential application is in urban forestry. Planting trees in the presence of natural gas lines, buried hydro cables, fibre optic cable, and the like requires knowledge of locations within 1 meter or less. Of course, this is contingent on there being accurate maps of buried services – which is not always the case.

As with most other areas where GNSS augmentation is applied, machine control associated with mining and construction is a growing and important business area, featured in a number of suppliers advertising materials and routinely mentioned by virtually all of those with whom we interacted while carrying out this study. While CanNet does not have many stations in mining areas, the mining sector is still the fourth most important to the company's business. Caterpillar is one of many suppliers of equipment that have entered into agreements with suppliers of what is commonly referred to as "GPS" hardware and services. (Often GPS is used as a short-form for GNSS augmentation including GPS and GLONASS.)

Today's equipment operators must comply with very specific and increasingly stringent requirements – some of which are legal or regulatory in nature. For example, in some open pit mines one must only remove a certain amount of material and this must be removed from exactly the correct place, or penalties will be incurred. (One can imagine the problems if one was to remove material from an adjacent property which the mine or quarry did not own or for which it did not have an extraction permit). In some mines one wishes to selectively mine certain areas to minimize both ore dilution at the processing plant and to reduce tailings or waste dumps. While seemingly a minor matter, the benefits can be measured in millions of dollars. In addition, one can now track each shovel full of waste from the processing location to a specific location in the waste dump. These applications were either not possible or very costly before GNSS augmentation. As early as 1999-2000 Leica Control (Accessed 2/3/15) cites North American Coal Company having savings of $200,000 per year by improved mining practices – they obtained a finished grade that is accurate to within ±2 inches with a machine that has a blade that is 13 feet high and 25 feet wide. They recouped the cost of the equipment in one year. Such examples abound in both the advertising material of most suppliers and the technical literature. The ACIL Allen study (2013) estimates benefits to mining in Australia were between $682M to $1.084B in 2012. With its significant mining industry, Canada (and Canadian companies operating overseas) can be expected to have also realized significant benefits from GNSS augmented services.

In construction, laying out a road base, or ensuring the proper slope on a curve in a road are all made easier by GNSS augmentation services. To ensure proper water flow, drainage channels must be dug with precisely the correct slope, and pipelines must be laid at the precise depth and slope called for in plans. Today these stringent requirements can be met without having a full survey crew on hand throughout the entire construction process.

Other applications that may not be so obvious include maximizing equipment deployment and utilization and minimizing the carbon footprint. This is done in several ways: by minimizing losses due to theft or unauthorized equipment use through the use of a “geo-fence” (the area beyond which the equipment will not operate); by saving on fuel costs and reducing emissions by monitoring and managing excessive idling; by responding to maintenance issues only when there is a need; and by optimizing productivity and reducing costs. One individual interviewed suggested that mining roads he had seen were often being graded constantly. He suggested that each of the heavy trucks could use augmented GNSS to travel on a slightly different path so that the trucks would play a role in keeping the road level, lowering the cost of grading and disruption of having a grader on the road in the path of the trucks. Whether or not this may be a useful approach one thing is certain: the GNSS community is looking at ways to help their clients improve their bottom line through the use of the technology. The cost savings can be substantial, especially when considered with the operational efficiencies introduced.

The last natural resource activity supported by GNSS augmentation services discussed here is the use GNSS augmentation services to return to the same precise location. This application includes field work associated with both exploration and environmental studies. While there are limits to the use of some of the GNSS technologies in the northern areas of Canada, the use of PPP to return to exactly the same place for field work is a significant improvement over more traditional methods that rely on, for example, local landmarks or GPS measurements accurate to five or ten meters. Commonly, field surveys for applications as diverse as crop plot assessments, environmental monitoring and research into changes in plants following permafrost melting must establish sample locations in remote areas where repeat observations must be acquired. Where these sample locations occur in remote areas PPP could provide more accurate positioning information to find these locations and improve the accuracy of re-sampling or re-visiting the same precise position. Similarly, where samples are being collected for mineral exploration, more accuracy and the ability to precisely record the sample’s original location is valuable. GNSS is also being used in some developing countries where Canadian mining companies are active, such as Zambia. Zambia is using GNSS (assuming not augmented) for processing mineral rights claims as well as to give more accurate locations for inspectors to visit (Mwalima and Mwila, 2006). Interestingly enough, Ontario has required the use of WAAS with 5 meter accuracy since November 2012 for claims in unsurveyed areas (Ontario, Accessed 2/4/15).

4.3.6. Natural Resources Sector Economic Benefits

Our preliminary analysis shows that the annual benefits of GNSS augmentation services in just mining and agriculture in Canada currently exceed $1 billion, and by 2020 should exceed $2 billion. Clearly, ensuring that these benefits are obtained, and that Canada keeps pace with competitors in Australia, the USA and Europe should be national priorities.

4.4. Public Safety and Emergency Management

4.4.1. Introduction

Public safety is taken to include all of those actions (usually undertaken by governments) to ensure the safety of the people. In some definitions public safety would include the military: for the purposes of this contract the military was specifically omitted. Public safety usually includes policing, ambulance or emergency services, and issues involving public health. Some aspects of public safety issues, including policing, forensic uses, and so called “ankle-tracking” associated with house arrest, for example, may use augmented GNSS. As well, there are applications relating to gas-line location for construction (or tree planting) that could also be considered to fall under public safety. Other aspects, such as public health, do not yet use such detailed information but, as noted elsewhere, there is great potential if “in-door” augmented GNSS use becomes feasible as some have suggested. Public safety is dealt with in Sub-Section 4.4.2.

Emergency management (EM), including disaster management or disaster risk reduction, is the act of avoiding, and dealing with risks from emergencies – whether man-made or natural. It involves making efforts before, during and after an emergency happens. In EM there is usually a continuous process to manage hazards in a collective effort to avoid or reduce their impact.

Satellite navigation has become an emerging positioning source for a wide range of EM and public safety applications, many of which are going much further than the traditional EM uses in the transport sector. Almost all of the current EM applications rely on GNSS signals, sometimes also exploiting regional or local augmentations for better accuracy. As applications move into safety-critical or other areas where service reliability is of concern, users and service providers alike are becoming aware of the importance of service quality and, ultimately, guarantees. As a first step, GNSS service integrity signals are already provided on such systems as WAAS and EGNOS.

Reliable meter level positioning is now possible with wide area corrections for core constellations with space based augmentation systems such WAAS in North America, EGNOS in Europe, MSAS in Japan, as well as a diverse array of Ground Based Augmentation Systems (GBAS) which all enhance service by improving accuracy, reliability and integrity via real time monitoring.

While many of the applications supporting emergency response and public safety are met by non-augmented GNSS capabilities, some are not, and the list of applications demanding the higher level of positional accuracy is growing.

4.4.2. Public Safety

GNSS, including augmented system applications, are slowly emerging in the public safety sector. Augmented GNSS comes into play in the tracking of emergency vehicles and responders by operation centres. There is growing use of augmented GNSS in police work, including forensic studies: that use is likely to increase (Kruger, 2009).

To date, the greatest impact of GNSS on public safety has been the inclusion of GNSS chipsets in personal cellphones. GNSS positioning for emergency services is already in use in several countries, notably the USA where positioning based on the use of wireless signals from cellular towers is an alternative to GNSS network-based solutions. GNSS functionality can be used by emergency services to locate cell phones. GNSS is less dependent on the telecommunications network topology than radiolocation for compatible phones.

4.4.3. Emergency Management

Introduction to Emergency Management Best Practices

Emergency and disaster managers have a "best-practices" strategy for minimizing the risk of disasters. The strategy consists of four phases: mitigation, preparedness, response and recovery.(Environment Canada, Accessed: 2/16/15). To put GNSS in context, this Sub-Section reviewed these four phases, while the following subsection details some of the specific applications.

Mitigation is an attempt to keep hazards from turning into disasters, or to reduce the effects of disasters when they occur. Mitigation efforts focus on taking long-term actions to reduce or remove the risk. Examples of mitigation efforts include: making changes to communities to strengthen them against hazards, building water barricades (such as levees) in the coastal zone to protect against storm surges; land-use planning and legislation (flood-prone areas can be designated as parks and non-residential), insuring against economic losses, and burying power lines to protect them from damaging weather. All of these actions can help reduce vulnerability.

Preparedness includes developing specific action plans to be followed when the disaster strikes. Mitigation may only go so far, and there may still be specific things to do when an emergency occurs. Examples of public preparedness efforts can include the following: developing easy-to-understand communication plans; developing and practicing multi-agency emergency cooperation; maintaining and training emergency services staff and operations; and stockpiling and maintaining large quantities of supplies and equipment.

Response includes moving the necessary emergency services and first responders to the potential disaster area. This could include activating emergency operations centres (EOCs), mobilizing the first wave of emergency services, such as firefighters, police and ambulances, mobilizing volunteer emergency response teams.

Recovery attempts to restore the affected area and bring things back to normal. The recovery phase begins once the immediate threat to human life has passed. Recovery actions include rebuilding, re-employment and the repair of essential infrastructure. Recovery efforts that reduce or eliminate future risk are also mitigation efforts.

The Role of GNSS in Emergency Management's Four Phases

GNSS based technology can serve to effectively manage disasters and provide early warning. The use of augmentation increases the accuracy and benefits of GNSS (Dixon and Haas, 2008). Its use in the four phases of emergency management is steadily growing and can be expected to contribute even more in the future.

Mitigation

Targeted networks with augmented GNSS capabilities will eventually be used to provide advanced public notice in case of certain emergencies: earthquake early warning appears to be one potential application worth pursuing. Studying the plate tectonic movement should eventually help in providing notifications and warnings for earthquake, volcanic eruptions and landslides. One might also include tsunami warning. PPP capable GNSS sensors could be placed on ocean buoys, along with other sensors, to detect wave motion and water level changes caused by underwater co-seismic activity.

Fencing areas of risk by imposing geographic and temporal boundaries of excluded activity has been used routinely. Distributing "limit of known icebergs" boundary to mariners at sea has demonstrated that ships would quickly alter course to avoid the fenced area (a collision with an iceberg within the boundary would void their insurance). Fenced areas also include no fly zone areas established for the 2010 Winter

Olympics in Vancouver, B.C. At the local level, they could be areas of known risk of avalanches or floods. It would appear that in special cases augmented GNSS may be required.

Preparedness
Providing greater accuracy in the mapping of critical infrastructure and known dangers (e.g. buried pipelines or power conduits) allows more rapid assessment of damage or potential hazards. Augmented GNSS is expected to play a limited role in most cases for the foreseeable future.

Response
Dispatching of first responders for most organizations cite a requirement of 20 meter accuracy except for police and fire services, who require 5 meter.   While stand-alone GNSS can meet the former, it requires an augmentations capacity, such as WAAS or EGNOS to meet all requirements. (Dixon and Haas, 2008)

Helicopter and other aviation requirements during emergencies are normally met by the more general GNSS standards of accuracy, i.e. not augmented. However, operating in austere conditions during large scale disasters in urban environments, with towers and power lines etc. is likely to push the limits of normal operations. In such cases, in the words of one author with command experience during real world Search and Rescue Operations, “one should anticipate an unanticipated demand for better accuracy”. Chassagne (2012) stated that “high accuracy navigation could enable helicopters, jets, and drones to fly close to the ground with little or no visibility even in difficult environments (such as mountainous and rocky areas). It will also benefit a number of civilian governmental users: police forces, agriculture agencies, geodetic survey and mapping agencies”

The future may see augmented GNSS used in dispatching drones, UAVs and even robots as well as activating and monitoring fenced areas of risk (unsafe areas near a mudslide, or downed live electrical wires).

Recovery
In the aftermath of a significant disaster event, augmented GNSS can serve as an essential enabling technology for a number of activities. The first of these is re-mapping, including re-establishing the legal boundaries of properties after major earthquakes that can involve substantial crustal motion and change. Cadastral data are used for property assessment, law enforcement, business location, transportation planning, national disaster response, and hazardous materials clean-up. It should be noted that such disasters may not be just natural disasters, environmental disasters or ones cause by war – they can also be economic.

While not usually needing augmented GNSS, there are other recovery operations that can benefit from GNSS such as responding for search and rescue, organizing debris removal, or planning long term recovery such as the World Bank’s Keith Bell, an Australian land surveyor, did for the areas affected by the Tsunami in Indonesia.

4.5. Science

4.5.1. Introduction[4]

The original contract and discussions with the client indicated that the primary interest in science was in GNSS augmentation that served the geosciences – measuring the spatial and temporal changes in various

[4] Much of the material in this section comes from UNAVCO, Personal Communication, Dr. Glen S. Mattioli, and Feaux et al, 2014, with additional material from Dr. Bisnath.

Earth systems, including crustal dynamics. Hence, the Plate Boundary Observatory (PBO) was suggested as a North-American system to profile. While there may be but a limited number of GNSS augmentation systems that have the capacity and accuracy to contribute to geodetic research, many of the other systems do support research in fields as diverse as crop science, soil science, environmental sensing, and many other research areas that require accurate positioning. In that sense, virtually all of the GNSS augmentation systems do support some aspect of research and this fact is worth noting as one begins to examine GNSS augmentation and science. One may also include precise orbit determination of scientific and remote sensing satellites, GNSS-based radio occultation for atmospheric science and weather forecasting, and GNSS-based surface reflectometry for Earth surface monitoring. All of these scientific and related activities require augmented GNSS.

The following subsections introduce the technical description of the PBO system, funding and investment, role of government, and applications, with special reference to its impact in Canada.

4.5.2. Technical Description

The Plate Boundary Observatory collects, archives and distributes data from over 1100 GPS sites located across the continental United States and Alaska. The PBO project has 891 permanent and continuously operating GPS stations and integrated 209 PBO Nucleus stations, which were previously part of legacy GPS networks, the total making up the current 1100 station PBO GPS Network. At any time 85% must be operational. It is currently being operated by the University NAVSTAR Consortium or UNAVCO, a non-profit university-governed consortium that facilitates geoscience research and education using geodesy. Part of the value of the system for research is the fact that 145 of the stations are co-located with meteorological stations while 25 are co-located with tilt instruments located on volcanic targets. A subset of about 100 stations is equipped with GPS+GLONASS receivers, and over 250 are expected to be GNSS capable by 2018.

Data are freely and openly available to the public, with equal access provided for all users. PBO data includes the raw data collected from each instrument, quality-checked data in formats commonly used by PBO's various user communities, and value-added products such as calibrated time series, velocity fields, and error estimates. Post-mission GNSS tracking data is provided by the UNAVCO Data Archive Interface that delivers what is referred to as “Normal-rate data” (15-second sampled) data or “High-rate data” (1-second and 0.2-second sampled) data. One may also request real-time GPS/GNSS data from the PBO network (UNAVCO, 2015).

Real-time processing of high rate GPS data can give precise (e.g., 5-10 mm for data recorded once per second) recordings of rapid volcanic and seismic deformation (Anderson et al, 2007).

4.5.3. Funding and Investment

The network was built between October 2003 and September 2008 for a total of $197 million under a program sponsored by the National Science Foundation. UNAVCO received funding for two operational phases: from October 2008 to September 2013 and from October 2013 to September 2018. The program is scheduled to sunset in 2018, although there are hopes for continuation. The NSF is encouraging UNAVCO to seek alternative ways to fund the maintenance of the infrastructure, data flow and archival process. At this time they do not charge for data, although a number of companies and others ingest their data, add value to it, and then sell the resulting product or service.

The annual budget for the GPS component is $9.3 million. 65% of that amount ($6.045 million) is for field operations and maintenance, while 35% or $3.255 million is for communications, data processing, archiving and products. Based on our assessment of the estimates available, $1.25 million would appear to be for communications. The PBO has very detailed information on the cost of maintaining stations, as well as the differences of costs from easily accessible areas where costs are as low as $4,200 per year to inaccessible areas where costs are as high as almost $14,000 per year. While these numbers may be useful in a general sense, caution should be used when applying similar numbers to Canada. The highest cost stations in Alaska are far closer together and far more accessible compared to, for example, those that would be located in Canada's arctic. With that caveat, the following two costing tables have been taken from Feaux et al (2014).

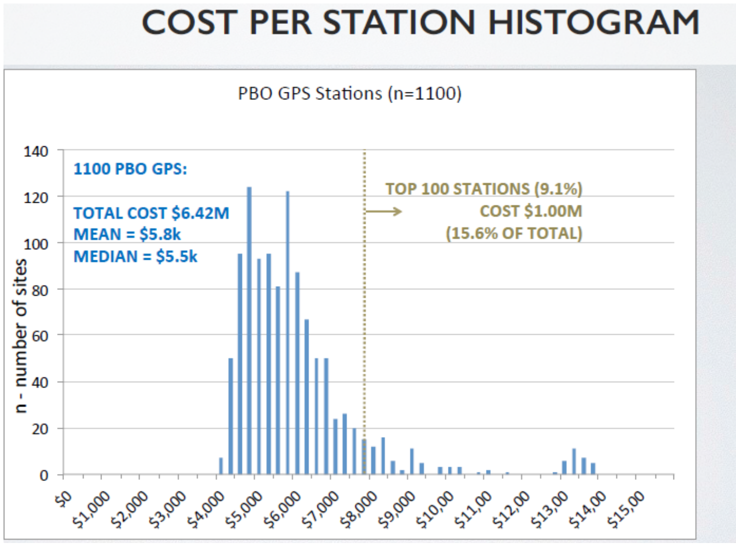

Figure 2: Cost Per Station Histogram (Source: Feaux et al, 2014).

MEAN COST PER STATION (1100 STATIONS)

	Mean Cost Per PBO Station Per Year
Field Operations Fixed Costs (Facilities, Storage, Shipping)	$255
Sub-Award Data Processing	$365
Archiving and Data Operations (staff, servers, software, etc)	$899
Realtime Data Handling	$305
Field Travel	$626
Labor (with fringe)	$1,267
Materials/Supplies/Equipment	$471
Station Permitting	$469
Data Communications	$386
Indirect Rate (15.79%)	$796
TOTAL	**$5.8k**

Figure 3: Mean Cost Per Station (Source: Feaux et al, 2014).

4.5.4. Role of Government

The US government role has seen it build and launch all of the GPS satellites, while the GLONASS satellites have been launched by Russia. The entire cost of the PBO system and its operation has been met by the US government. The total to date including maintenance approaches $300 million. This does not count the cost of the satellites, which was, as noted above, $5 billion in 1995 dollars. Jacobsen (2007) quotes a US military presentation saying that the US has spent more than $26 billion through 2006 developing and deploying the GPS satellites and equipping its forces and weapons systems with the technology.

4.5.5. Applications

The core scientific objective of the EarthScope activity which supports the PBO is "quantifying three-dimensional deformation and its temporal variability across the active boundary zone between the Pacific and North American plates,….with far reaching implications to the dynamics of plate-boundary-zone deformation, earthquakes, and volcanic processes" (UNAVCO).

UNAVCO further notes that the "declining costs of geodetic instruments (both GPS and GNSS) and data communications, improved precision, and enhanced data processing, increased computing power, and corresponding advances in model sophistication have allowed the scientific community to better address an array of critical scientific and societal problems using space and terrestrial geodetic data—in geographically distributed areas." These range from identifying previously unknown seismic zones to finding large amounts of water deep under the US land mass. The latter was published in ***Science*** (Schmandt et al, 2014). A more detailed outline of the science plan to 2020 is given on the Earthscope web site at http://www.earthscope.org/information/publications/science-plan/

The Geological Survey of Canada is listed as a participant in the PBO. More specifically the work by recently retired Dr. Herb Dragert of the Pacific Geoscience Centre was mentioned in our interview and he was the only Canadian participant in the Science Plan referred to above. Dr. Dragert was appointed to the Board of Directors of UNAVCO in June 2003. His biographical sketch on the NRCan web site notes that his research has focused on the study of crustal deformation within active seismic areas on the west coast of Canada using geodetic techniques such as leveling, precise gravity, laser ranging trilateration, and GPS. Beginning in 1992, under his direction, the Geological Survey of Canada established the Western Canada Deformation Array, the first continuous GPS network in Canada for the express purpose of monitoring crustal motions. It was data from this network that provided the key information which led to the discovery of "Episodic Tremor and Slip" in the Cascadia Subduction Zone.

Dr. Dragert has also led Canadian involvement in the PBO's parent EarthScope program which has resulted in a cooperative effort for more intensive crustal deformation monitoring along the Cascadia Subduction Zone, including the first installation of borehole strainmeters in Canada. That work is of significant value inasmuch as it involves assessing plate tectonics on the west coast and the potential implications for what scientists would call a major seismic event – a devastating earthquake. The probability of such an earthquake occurring in the next 50 years has been estimated at 30%: it is not a question of whether there will be a major and devastating earthquake, but rather when.

The outcome of the work by Dragert and the PBO suggests the possibility of predicting the precursors to earthquakes. Similar work has been done in Japan on this subject by Prof. Shunji Murai (Murai, 2012 and 2013). Using GPS data provided by the Japanese Geospatial Information Authority (GSI), Murai's group claims to have predicted (after the fact) the Great East Japan earthquake of 2011 through trend analysis of time sequential data using 1,200 GPS stations. This was done five, four and three weeks before the earthquake. The most critical pre-signals were three weeks before the earthquake, although the signals weakened afterwards until the earthquake occurred. Murai and his team are developing a business that will provide a commercial service for earthquake prediction.

Looking at the results of Dragert and Murai the cost of $300 million for the PBO activity pales in comparison to the estimated cost of a major earthquake off Vancouver Island. A study on the potential impact was sparked by concerns over the extensive damage from earthquakes in Chile, Haiti, Japan and New Zealand in 2010 and 2011. In 2013 the Insurance Bureau of Canada sponsored study projected that a severe earthquake off the south coast of B.C., followed by a tsunami, would cause $75 billion in damages to buildings, bridges and pipelines (Insurance Bureau of Canada, 2013; Guin, 2013; and Hoekstra, 2013). The costs would come from interruptions in business and services. Even a fifteen minute warning could save billions of dollars and many lives if, for example, pipelines could be shut down, low areas and buildings evacuated, bridges cleared, etc. The IBC says the study shows that B.C. and Canada (including potential damages of $61 billion in Quebec) are not prepared for the "big one."

4.5.6. Science Sector Economic Benefits

What began as a highly research-oriented program studying a complex area of geophysics has yielded results that shed a light, however dim, on earthquake prediction – a subject of critical interest to the people and governments of Canada. What role might the PBO play in mitigating the impact of a major earthquake? Until this question is answered, this would appear to be an area that requires more research and continued support for the infrastructure that will allow the even more basic question to be answered: will GNSS augmentation services help predict earthquakes with sufficient warning to mitigate their most devastating impacts on loss of life and property damage?

4.6. Land Survey

4.6.1. Introduction

Originally the client intended that land survey would be included in Natural Resources. However, in the course of carrying out this study, it seemed more appropriate to add land survey as a separate class for several reasons. First, it was found that land survey was an important (and sometimes the most important) application of GNSS augmentation services for many of the commercial suppliers – even for those like John Deere's NavCom whose original market was in agriculture. Second, since land surveying is a regulated profession, there were more stringent regulations and demands placed on the GNSS services in this sector than is the case for natural resources. Third, in this study and others we have conducted, we have found that many of the RTK stations are co-located with or hosted by land survey firms – those firms are often involved in maintaining stations for a reduced cost for access. Lastly, land survey is becoming of increasing importance in the developing world, as can be seen in any analysis of World Bank Projects, bi-lateral aid projects, and the World Bank's annual Conference on Land and Poverty. Interestingly enough, the group that represents the profession internationally, FIG, has but 110 countries in the fold, although it does have MOUs with a number of UN agencies to assist with surveying issues in developing countries. In 2004 the UN estimated that there were 230,000 land surveyors (United Nations, 2004). In Canada there are approximately 3000 provincial land surveyors. With this importance come opportunities for the use of augmented GNSS and the export of Canadian expertise and technology in precise location.

To avoid repetition, the following subsections introduce only the aspects of the systems that are unique to the land survey sector in terms of the technical description of the system, funding and investment. With the regulatory regime in land survey the role of government is different from, for example, the natural resources sector and this is dealt with in Sub-Section 4.6.4 while the applications are considered in Sub-Section 4.6.5.

4.6.2. Technical Description

The technical descriptions of RTK or PPP services remain the same as previously described. Whether the major providers involved provide RTK or PPP augmentation services, they all identify cadastral mapping or land survey as major applications.

The CanNet service based on Trimble equipment, which has the largest network of CORS stations in Canada, is profiled here to outline its main characteristics. With 300 stations across Canada, it covers almost every major population centre and farming area. It is said to be the fastest growing network in the country with 1500 users accessing its 24/7 high-reliability service. Part of its new service is a detection system to determine if there are any issues with the primary system. If there are, the system will automatically switch to a back-up with no loss of service. Given that the system is supported by five servers, there is excellent redundancy in addition to the dual operating systems. CanNet also has a cell-phone service agreement with Rogers and Bell that provides access with data-only SIMs.[5] With 1 cm horizontal accuracy, CanNet claims 15-20% savings over traditional RTK services and can bill usage by the minute.

4.6.3. Funding and Investment

Using the minimum investment for basic hardware, and the estimates provided by Australia for additional items such as solar panels, equipment hut, batteries, communications, etc., the cost per station can be from $25,000 to $50,000 each. The 300 stations operated by CanNet could then have a cost of from $7.5 to $15 million. Additional costs for servers and communications might account for $1 million. This does not count the investment in rover units by government or land surveyors. However, if 35-50% of the RTK stations and the servers that control them in Canada are used for land survey, then the investment in support of this field by the GNSS augmentation services industry likely exceeds $20 million. This does not include what the land surveyors have spent or the on-going maintenance and other costs detailed in Tables 2 and 3 above.

The ACIL Allen (2013) report on benefits in Australia “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.” If we take these values and apply them to Canada, a much larger country with more parcels to survey, the annual economic benefits would far outstrip the total investment in the stations and the federal government’s support for geodesy.

4.6.4. Role of Government

CanNet is very clear on the important role of government in the service it provides. Indeed, they use the endorsement of CGS in their promotional material: “Federally accredited coordinates: Can-Net 3.0 is using co-ordinates calculated, provided and endorsed by the Federal Government for all our base stations.” Previous studies confirm that people trust government agencies to give legitimacy to issues like the accuracy of land survey boundaries. Given the degree to which Canada’s economy depends on land ownership, the importance of the government’s role in augmented GNSS cannot be overstated in the land survey context.

4.6.5. Applications

Land surveyors operate in a regulated environment with standards for accuracy that must be met. While the explanation of standards is complex for those not well versed in geometry, they can simplified to say that land survey requires precision within 2 cm. (Alberta Association of Land Surveyors, 1999) Furthermore, in the same guideline for land surveyors, it is stated that “the measure of accuracy for surveys conducted in whole or in part with GPS techniques” must meet this standard. Simply stated, before the intentional degradation of GPS capabilities was removed in 2000, GNSS systems could not

[5] SIM - A SIM or Subscriber Identity Module is a removable smart card for mobile phones.

deliver the accuracy required for legal surveys. That has changed, and changed dramatically. As long ago as 2005 Rizos et al (2005) stated that "*the surveying and mapping industry has been revolutionised by the use of Global Navigation Satellite Systems (GNSS), involving satellites, ground reference station infrastructure and user equipment to determine positions around the world*." However, in the same paper they also posed some questions about some of the limitations. Today those limitations have been removed. GNSS RTK augmentation routinely delivers the required accuracies in targeted regions while PPP solutions do almost as well, anywhere. This has led to widespread adoption of GNSS augmentation services by the land surveying community in Canada and elsewhere for cadastral surveys as well as for surveys dealing with construction and resource use.

Testimonials by land surveyors presented on the web sites of the major service providers (e.g. CanNet) clearly demonstrate that the service is both well used by the professional surveyor community, and cost effective. Some RTK service providers have indicated that land survey makes up 50% of their business. All providers who operate on land confirm that land survey is one of the top application markets.

4.7. Emerging Sectors

This subsection looks at what sectors may emerge as important in the future – it can be regarded as a "blue-sky" exercise compared to Section 6 that reports on trends seen by respondents and participants in this study.

Over the past fifteen years the use of precise location information has exploded. Precision agriculture has gone from a dream to a well-documented reality. GPS has gone from being an interesting toy in expensive automobiles to having largely replaced road maps for many of us. Satellite imagery that was once a tool used by a few tens of thousands of specialists world-wide is now available to hundreds of millions. Along with this advance in precision and access to information have come new models for delivering and using these tools. With this background and the benefit of a combination of a high level perspective tempered with long experience, we believe that four new sectors may emerge:

- **Indoor Applications.** 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 in areas such as security, health (tracking equipment movement and people movement to track infection movement, for example), and retail.
- **Monitoring Coastal Zones** To date the value of GNSS has most often been associated with pinpointing a location. In the future, sea level rise will have a profound impact on humanity. As sea levels do rise, heights will become more important and monitoring coastal zones will become a major area of focus;
- **Earthquake Readiness** The financial and human costs of earthquakes and the resulting tsunami's and other natural events have been well documented. GNSS is already used in the Public Safety Sector in countries as varied as Bangladesh, Canada, and Japan. While such use will grow in importance, there would appear to be the potential for GNSS augmentation services to contribute to predicting the near term potential for major seismic events.
- **Mobile-connected Individual** A standard refrain for those who look to the future is that the world is becoming "mobile." Everyone has a cell phone, and most cell phones have a built-in GPS. We can assume that there will be an entrepreneur somewhere who will build a business that will in some way link an individual's mobile device to more precise location.

As we consider what future sectors might emerge, further "blue-sky" questions on the future can be posed:

- What role might GNSS augmented services play in the growing area of establishing land or tenure rights in developing countries?
- Will there be a role for advanced cell phones or mobile devices in more precise location-based services in Africa and other developing regions?
- Will UAVs really be able to deliver parcels?
- Are there implications for robotic systems?
- While precision of 1 cm is currently restricted to location outdoors, the technology leads one to ask questions about the implications for precise location indoors. Are there potential implications in health care following on what the company Infonauts has done with tracking inside hospitals?
- What precision will be required for driverless cars or other autonomous vehicles?

4.8. Estimating Investment and Operating Costs for Augmented GNSS Systems Used in Canada

4.8.1. Introduction

The client has defined the investment in augmented GNSS in Canada of interest here to be that investment up to the point where the data are distributed to the users. Obviously the users have also invested in the technology – be it a receiver as part of land surveying equipment or a guidance system on agricultural machinery or construction equipment. Users also pay for communications – increasingly using relatively low cost cell-phone technology. Given that there are many thousands of users, and the investment can be as much as $15,000 or more per user, this "user investment" will obviously be significant – many millions of dollars. Of course, given that the benefits of truly disruptive augmented GNSS technology have been estimated in the hundreds of millions of dollars, it is only reasonable to expect that the cost of implementing the technology by the beneficiaries would also be in the tens of millions of dollars.

Here we consider four primary sources of GNSS augmentation: the national geodetic networks – including the Canadian Active Control System (CACS) and related systems, the commercial RTK networks, the systems used for aviation (WAAS), and DGPS used for marine transportation. Global PPP systems are not included as the investment made by companies in this specific area is not available, whether for Canada or the rest of the world, although financial estimates for PPP infrastructure are provided.

4.8.2. The Governmental Geodetic Network Infrastructure

The foundational reference frame for augmented GNSS in Canada depends on what we call here the geodetic active control network. This network is largely funded by the federal government. While primarily funded and operated by the Canadian Geodetic Survey (CGS), other players contribute – such as the Canadian Hydrographic Service - which supports the co-location of GNSS receivers with tide gauges along the coast and inland waterways. About one-half of the seventy-one stations are used to contribute to the global IGS network that provides the precise GNSS orbit products that feed Precise Point Positioning services. This contribution allows NRCan to offer free 'post-mission' PPP solutions from an online service. Private companies also have their own global tracking networks to provide commercial 'real-time' PPP solutions to their customers around the world. The remaining one-half of the stations contribute to specific applications such as tracking crustal dynamics, weather forecasting and water level monitoring. In addition to the CGS, several provinces provide access to CORS data, including British Columbia (and Metro Vancouver) with seven stations, Quebec with nineteen, and Nova Scotia with twenty (to be increased to forty). The lifetime cycle for equipment replacement is 7-8 years for the main components *i.e.* the GNSS, computing and communication hardware.

Table 4: Geodetic Network Infrastructure - Capital and Operating Costs		
	Capital Cost[1]	Operating Cost/Year
Federal Government	$2,132,000	$296,000
Provincial[2] and Municipal Government[3]	$ 780,000	$ 78,000

[1]Almost 95% of the value of the systems must be replaced every 8 years. This further assumes that new stations in the north will be funded. All values are based on the actual budget for the federal government and estimates for the other levels of government.
[2]Nova Scotia's twenty systems are covered under the RTK investments in the next subsection.
[3]The municipal government reported larger costs, but they were not all related to augmented GNSS.

4.8.3. Commercial RTK

In Canada there are 605 commercial CORS stations operated by a number of private sector entities. All of these stations are in relatively accessible locations, and all companies have multiple servers to compute network solutions and distribute corrections. We have been told that one server can support up to 100 stations. Given the back-up servers, and the number of stations operated by each supplier, we can assume that there may be as many as 15-20 servers. From Table 5, the cost estimates for industry's investment in commercial RTK is approximately $19.5 million, and annual operating costs are in the vicinity of $3.3 million. It should be kept in mind that these stations are all close to populated areas and that this is a rough approximation. In most cases technical staff do not work full-time on servers or maintenance – they are a shared resource. Operating costs include costs such as software licenses, communications, site visits, etc. See Section 4.5.3. Costs associated with marketing, sales, customer support, administration, and the like are not included.

Table 5: Private Sector RTK Capital Cost and Operating Costs

	Number	**Initial cost (Estimate)**	**Total Investment**
Number of Stations	605	$30,000.00	$18,150,000.00
Number of Servers (Estimate)	20	$70,000.00	$1,400,000.00
Total Investment			$19,550,000.00
	Number	**Operating Cost (Estimate)**	**Annual Operating Cost**
Number of stations	605	$5,000.00	$3,025,000.00
Number of Servers (Estimate)	20	$15,000.00	$300,000.00
			$3,325,000.00

4.8.4. WAAS

We have provided an estimate of the cost for the USA portion of WAAS in Sub-section 4.2.4. NavCanada has the responsibility to operate the network stations located in Canada. NavCanada regards the information of its capital and operating cost to be proprietary.

However, one major investment not accounted for, but which is entirely made because of WAAS, is that of the navigation systems on aircraft. One contact has told us that the navigation system on his twin-engine aircraft cost $60,000. One can assume that the WAAS capable navigation systems used on the 520 aircraft operated by Air Canada, WestJet and Porter[6] would have systems at least as sophisticated and costly, representing an investment of over $30 million. This does not count other commercial passenger and cargo airlines, or the 16,293 certified private aircraft in Canada (Canadian Owners and Pilots Association, 2014).

While the investment in WAAS may be significant, the next improvement on the horizon, LAAS, will require investment by airports. Since this investment has not yet been made and since it does not appear to have been adopted yet in Canada, it is not included here.

4.8.5. DGPS: The Canadian Coast Guard Next Generation DGPS

The Canadian Coast Guard (CCG) has operated their Differential GPS (DGPS) service for many years. The 19 CDGPS stations along the Atlantic and Pacific coasts and St. Lawrence waterway use radio-beacons to broadcast GPS corrections to mariners. This supports navigation with meter precision. The CDGPS network is nearing the end of its life, and the CCG is actively pursuing its complete recapitalization. While historical costs were not readily available, estimates developed for internal lifecycle planning purposes were shared by the Canadian Coast Guard for this report. These costs are summarized in Table 6, below.

Table 6: Canadian Coast Guard Next Generation DGPS Estimated Capital and Operating Costs

	Capital Cost	Operating Cost/Year
Federal Government	$28,275,800[1]	$419,500 [2]

[1]Assumptions include 19 operational sites, 1 Canadian Coast Guard College training site and 1 support technician site will be funded.
[2]This estimate above is based on salaries for life cycle management, regional CCG support, communications, IT training, office supplies, etc. At around 1.5% of the capital costs, it may in fact be low.

4.8.6. Precise Point Positioning (PPP)

We have been asked to estimate within an "order of magnitude" what the investment has been by the private sector to implement a global Precise Point Positioning (PPP) capability. Given the highly competitive nature of the business – there are several world-class companies competing in this market space – industry refuses to provide such sensitive information.

We have therefore taken an approach that tries to come at this estimate from two directions – 1) building up what it might cost based on certain assumptions about station, computing and communication costs and network size and 2) evaluating the limited information found in the open literature, including annual reports and business transactions. In other cost estimates provided here we have focused on the investments in Canada. However, PPP is a world-wide service. Isolating what amount of the total investment can be attributed to Canada is simply not possible.

[6] Air Canada and Air Canada xpress have a total of 368 aircraft (A/C). http://www.aircanada.com/en/about/fleet/ ; Westjet has 126 A/C http://en.wikipedia.org/wiki/WestJet ; and Porter has 26 A/C http://en.wikipedia.org/wiki/Porter_Airlines

In Table 7 we build an estimate of costs from the "ground up." To do so a number of assumptions are made about the investment made by a company – any one of which may be in error. As an example of the assumptions made, the open literature contains information on the number of servers and back-ups reported by one supplier. We also know that major service providers for which we have obtained numbers of stations (Trimble, Hexagon, and John Deere) appear to have between 80 and 100 such stations each. (Fugro sold its land-based PPP business to Trimble and we count Fugro together with Trimble for this exercise.) For operating costs we use an amalgam of the estimated costs from the Australian government and industry for the establishment of a station, the cost of servers, and maintenance costs. While one might assume that some of the maintenance and associated costs are shared with other activities within the company, we have not made that assumption here.

The more difficult estimate is that of the algorithm development and other R&D costs, R&D and engineering costs to turn the solution into a service. These have been derived based on costs with which the senior author is familiar in developing another service based on satellites and positioning. **It should be emphasized that these are order of magnitude estimates: any one of these costs may be significantly higher or lower than what is presented here.**

Based on the assumptions in Table 8 that follows, the estimated investment is on the order of $14 million, with an annual operating cost of over $3 million. The operating costs do not include sales and marketing costs, which, as can be seen from the various companies' web pages, are substantial. It does not count customer support, or on-going R&D and product/service development and improvement. Since there are, in effect, three main players, this leads to an investment by the private sector of something on the order of $30 to $40 million, perhaps more, but likely less. Annual operating costs for three players might be as high as $9 million.

Our test of these numbers comes from an annual report of one of the major players – Hexagon. In reporting the purchase of Veripos, a PPP service provider, Hexagon reported that the valuation was composed of several elements. Goodwill of €103.0 M was "the value of expected synergies arising from the acquisition and the assembled workforce." A total of €23.3 M was made up of intangible assets. Of this €8.8 M was assigned to trademarks that are not subject to amortization. The remaining €14.5 M was assigned to "capitalized development expenses, patents and other assets with useful lives of 7-15 years. The intangible assets have been valued using a discounted cash flow method." We assume that "the capitalized development expenses, patents and other assets with useful lives of 7-15 years" is the value of the investment in PPP, but with the implications associated with using the discounted cash flow method for valuation. Without getting into too much detail on cash flow evaluation[7], and given that there are no other sources to verify the number we have arrived at for an estimate, we will use the €14.5M, which in December 2014[8] would have been $17.6 million. "From the date of acquisition, Veripos has contributed €34.2 M of net sales in 2014. If the acquisition had taken place at the beginning of the year, the contribution to net sales would have been €37.1 M." (Hexagon, Accessed 3/10/15)

[7] The use of discounted cash flows is a way of taking an expected payoff from an investment in the future, and putting it in terms of today's money. In other words, discounted cash flows take into account the so-called time value of money, i.e. the fact that one dollar 10 years from now is worth less than $1 today. In this case it is not a one-for-one valuation of the development costs, but rather the future value of the development costs discounted for the time value of money. Without knowing the specific valuations, cash flow projections, interest rates and the initial investment, it is difficult to directly relate the discounted cash flow to the initial investment, but this is the closest number we could locate for validation.

[8] The Euro to dollar exchange rate on December 31, 2014 was 1.2156 See http://www.freecurrencyrates.com/exchange-rate-history/EUR-USD/2014

The world-wide investment by industry in developing PPP technology and services is estimated to be on the order of $30 to $40 million US. Operating costs for three main suppliers might be as high as $9 million. It should be noted that there are many caveats and assumptions associated with these estimates, as are explained in Table 7 on the next page.

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Table 7: PPP Investment and Operating Cost Estimate					
Item	**Assumptions**	**Unit cost (in $1000)**	**Number**	**Total Invested (in $1000)**	**Operating Cost/year (in $1000)**
Station creation	Most housed at dealers; some in difficult environments; we use 1/2 of Australian costs.	75	100	7,500	
Station operating	Assume $10,000 per year per station for maintenance – we use double PBO since some are remote requiring more travel – this is likely an over-estimate	10	100		1,000
24/7 technical coverage	Assume 1.5 technical people available 24/7; 3 shifts per day for 365 days = 7.5people to cover 220 work days. Most technical support staff would likely have other duties.	80	8		640
Servers	7 servers/systems	70	7	490	
Server maintenance	24/7 server coverage will cover some of maintenance; this cost is for software, travel support, etc. Most technical support staff would likely have other duties.	7	7		49
Software maintenance	3 people (based on service levels provided for another satellite positioning service with which the author is familiar)	125	3		375
Communications	Dedicated satellite communications. (Estimate provided by NRCan)	1,000			1,000
Algorithm development	5 person years at $125K / year. This estimate does not take into account that GNSS engineering and computer programming staff tend to also work on other related company activities, e.g., RTK software, customer applications, etc.	150	5	750	
Systems engineering to build service	15 person years for software; 10 person years for hardware. Based on number of authors of key papers published by one supplier and when they appeared to work for the company, plus costs for a related service Many of these same authors do write on subjects other than PPP. This estimate does not take into account the fact that that GNSS engineering and computer programming staff tend to also work on other related company activities, e.g., RTK software, customer applications, etc.	135	25	3,375	
Marketing	Hard to estimate - trade shows, beta tests, conference papers usually >10 to 20% or more of development costs and 10-15% of income.. Of course PPP is not usually isolated from other products and services in marketing.	$1,800		1,800	
University research?	We do not have estimates of what the industry may have funded – or what university research led to commercial success. Interaction with universities ranges from sending employees to pursue degrees, to purchasing algorithm functionality to no contact			?	
Beta testing ?	We do not have estimates of beta testing costs/demonstrations – such tests were reported in the literature. Some beta testing has been done in universities with very little cost.			?	
Other costs?	What other costs might there be?			?	?
Total investment	This number may be high, but is presented as an order of magnitude estimate.			$13.915M	
Annual operating cost	This number may be high, but is presented as an order of magnitude estimate.				$ 3.064M

4.9 The Role of Federal Government Departments and Agencies: Present and Future

4.9.1. Introduction

Earlier in this Section we reviewed *"the role Government plays in different business models used to deliver GNSS augmentation services*" in each of the major sectors. While that detail met the requirements of the contract, it does not address the more fundamental question of "What should the role of government be?" and "What will the role of government be?" The next Sub-section provides a summary of the role currently being played by the Federal GNSS Coordination Board (FGCB), further details are found in Appendix C, as is an analysis of the roles that are played or could be played by various Federal departments or agencies in light of the future trends and technology developments identified elsewhere in this report.

4.9.2. Federal GNSS Coordination Board (FGCB)

The FGCB was established in September 2011 under the auspices of the Public Safety Canada's Assistant Deputy Ministers' Emergency Management Committee (ADM EMC). Many of the key federal agencies and departments are already involved through contributions to the FGCB. The FGCB was established because the government recognized the importance of GNSS in the broadest sense – for the purpose of positioning, navigation and timing (PNT). The objectives of the FGCB are "*to collaborate, share information and expertise, provide advice and act as a central point of contact for the coordination of federal GNSS issues*."

Members with an interest in GNSS include Industry Canada, Natural Resources Canada, Fisheries and Oceans Canada, Transport Canada, Foreign Affairs, Trade and Development Canada, Public Safety Canada, the Department of National Defence and the Canadian Space Agency.

4.9.3. Conclusion – Role of Government

Our analysis, presented in Appendix C, suggests that other agencies of the federal government could or should be engaged. The technical nature of the mandate and activities of the FGCB would seem to preclude involvement of what we call "user agencies" or "user departments" in that committee. However, it would appear that some form of user committee and perhaps a national advisory committee would provide a useful and valuable voice in shaping an understanding of the future requirements to ensure that Canada's needs are met in terms of what augmented GNSS can and does deliver

5. Regional Comparison

5.1. Introduction

This section examines what is being done in the United States and Canada in comparison to Europe and the Asia-Pacific region in GNSS. An important part of this is an analysis of the relative activities by governments, the widely different context found in each region and the resulting level of sophistication and up-take of the technology. Special attention is paid to Australia and Korea, part of the Asia-Pacific Region, because of similarities in certain respects to Canada. There is somewhat more detail on Asia inasmuch as Asia is more complex, less uniform, and is rapidly developing its capabilities in GNSS augmentation. The following three sections provide a summary of each region's situation, followed by a concluding section and summary table.

5.2. North America

The bulk of this report to this point has focused on GNSS augmentation services supplied to North America. The concept of GNSS was born in the USA (during a weekend meeting of air force officers) and was first commercially exploited in that country. The cost of the satellite system alone in 2015 dollars would be $7.85 billion[9]. The obvious importance of the satellite systems has been stated by many. Perhaps the most clearly it has been stated was by Trimble in its filing with the US Securities and Exchange Commission. With over $2 billion in sales related to GPS, Trimble lists the failure of keeping up the satellite systems as a major risk to their business.

While two major commercial players are still US-based and US-owned, several other key players are owned by two European companies and one Japanese company. Regardless of ownership all of them have a significant presence in the USA, as one would expect given the military importance of the technology to the USA. Only one of the fully commercial services offered in Canada is provided by anything other than a company with a global or near-global reach. That company, operating the CanNet RTK service, uses technology provided by Trimble, one of the major global players.

Unlike Europe or Asia, North America is far less fragmented. Cooperation and agreement is easier to obtain between the fewer players. Canada and the USA do cooperate on both WAAS and DGPS, and the PBO links Earth science researchers on both side of the Canada/US border. While some of the global players have placed relatively more CORS stations in Canada than in the USA, that can be seen more a function of the size of Canada and the perceived value of the market than a measure of what Canada has contributed to the programs. Canada and Mexico may be partners, but compared to the USA they are minor partners.

There are, however, significant differences between Canada and the USA. These differences can be seen most clearly when comparing the CORS sites in the USA and those in Canada. In Canada we have identified a total of approximately 135 CORS stations operated for the federal, provincial and municipal governments, including the Canadian Coast Guard, Canadian Geodetic Survey, and Governments of Quebec, Nova Scotia and British Columbia. The twenty CORS stations in Nova Scotia are operated by the private sector for the province. A similar situation exists in several states. These twenty sites in Nova Scotia are included in the 604 sites listed for the private sector. The USA lists over 2500 CORS stations[10] (National Geodetic Survey, Accessed 3/17/15). Of these over 1020 are owned or controlled by state departments of transport and several hundred others are operated by other state agencies and municipalities, while some 434 are PBO stations, and another 394 are operated by the US Coast Guard. Of the 2500 more than 100 are operated on behalf of state governments by the private sector.

While taking into consideration the different levels of population, area and the like, there appears to be far more investment by US governments in RTK technology than there has been in Canada. Perhaps most telling is that private sector companies operating in both Canada and the USA have told us that while state services are free in some instances, some users would rather buy commercial services than obtain free services from government. These same private sector people have stated that the Canadian government activities in this domain are essential inasmuch as the Government of Canada provides the validity for the commercial entities activities. In most cases it is assumed that the Canadian economy is 1/10 that of the

[9] The original cost was $5 billion in 1995. This was converted to 2015 dollars using http://www.dollartimes.com/calculators/inflation.htm

[10] It should be noted that of these 2500 stations some 50 are listed as “non-operational” while another 587 are listed as “decommissioned, leaving closer to 1900 active stations.

USA. If that is the case, and considering that there are 46 CORS stations operated by municipal and provincial governments in Canada, we would assume that the USA would have something on the order of 460 CORS stations operated by state and municipal governments. In fact, the number is more than three times that. If we exclude the 394 Coast Guard CORS stations, there are 1500 operating CORS stations in the USA. Their initial cost would be $45M. If we assume that there are two servers per state and another ten for federal agencies (likely an underestimate), then the 110 servers would cost almost $8M. Excluding the cost of WAAS to the FAA, and the respective coast Guards in the two countries, then the total investment in RTK in the USA would be $53M, twenty times what Canada spends.

In summary the following factors have created a very different dynamic that separates North America from Europe and Asia:

- The USA was the acknowledged early leader, having developed the first operational GNSS technology;
- Canada and the USA are allies in the political and military sense. The USA and Canada worked together on some of the early military uses of GPS and preceding technologies for various guidance systems. This work established trust in a sensitive area first housed in the military;
- The USA was the first to approve the release of the technology for use in the private and civilian sectors;
- The US Government provides the satellite infrastructure;
- The USA and Canadian Governments provide services related to public safety, geodetic science, and service in remote areas. The USA government provides far more than does the government of Canada;
- State and municipal governments provide far more CORS stations than equivalent agencies in Canada;
- The USA and Canada have developed a cooperative arrangement for both air navigation and marine navigation;
- The USA and Canada have developed cooperative research programs; and
- Canada and the USA have not seen their government to government arrangements in GNSS as competitive, although industry in the USA does see state activities to be competing with industry.

5.3. Europe

5.3.1 Introduction and Overview

Our report is to consider GNSS in Europe compared to North America. What is "Europe" in this context? Europe is made up of several distinct communities. First is the European Union (EU), composed of what are often referred to as Western European and Nordic countries as well as more recent additions from what was once called Eastern Europe. The second community is Russia. A third group is composed of those countries that are not in the EU or not engaged in the European Space Agency (ESA). Here we profile the EU in Subsection 5.3.2, followed by Russia in 5.3.3.

5.3.2. European Union

Introduction

On the political space side, there are longstanding mechanisms within the European Union (EU), and the European Space Agency (ESA), that attempt to overcome the tendency to regard precise positioning and land survey as a responsibility of the nation-state as opposed to the European collective. It was ESA and the EU that officially launched the concept of the Galileo GNSS in 2003, and the GNSS went operational in 2013, when the first determination of a ground location using the four Galileo satellites currently in orbit together with their ground facilities was made (ESA, 2013).

Soon after, in 2004, the European GNSS Agency (GSA) was started. "*The GSA, an EU Agency, is currently responsible for a range of activities related to the European GNSS programmes (Galileo and EGNOS) including:*

- *Preparing for the successful commercialization and exploitation of the systems, with a view to smooth functioning, seamless service provision and high market penetration;*
- *Ensuring the security accreditation of the system and the establishment and operation of the Galileo Security Monitoring Centres (GSMC);*
- *Accomplishing other tasks entrusted to it by the European Commission, such as, managing EU GNSS Framework Programme Research; the promotion of satellite navigation applications and services; and ensuring the certification of the systems' components*" (European GNSS Agency, Accessed 2/8/15).

Another manifestation of Europe moving into the geospatial domain was the creation of the Infrastructure for Spatial Information in the European Community (INSPIRE) in 2007 (European Commission, Accessed 2/18/15).

In effect the GSA is the "government" R&D and marketing arm for the Galileo program. While it provides a list of component and service providers (over 800 of them) at its web site, it is the GSA that leads international activities. In effect, this is similar to how the Canada Centre for Remote Sensing helped sell the fledgling Canadian remote sensing industry from the mid-1970s through the early 1990s. This is, of course, a marked departure from the past and current situation in the USA. In the USA the government provides the satellites, R&D, and calibration; while industry provides the marketing and commercialization. When the GPS service opened up in 2000, the US government did carry out international awareness activities. These activities followed Vice President Gore announcing (in 1999) "plans to modernize GPS by adding two new civilian signals to enhance the civil and commercial service." (Clinton, 2000) The US activity did not have quite the same commercial focus as the GSA seems to have.

The GSA has been actively marketing in Asia, specifically in India, China, Taiwan, Republic of Korea, and Japan (European GNSS Agency, Accessed 2/18/15). It has also held seminars to which those from many other countries have been invited.

The balance of this section on Europe details some of the major programs operated by Europe as a whole, as well as those operated by Russia. Appendix D provides more specific country detail to round out the description.

European Regional Services and Activities

The European Geostationary Navigation Overlay Service (EGNOS)

EGNOS is Europe's first venture into the field of satellite navigation and paved the way for Galileo. EGNOS is the European Space-Based Augmentation Systems (SBAS), similar to the US Wide Area Augmentation System (WAAS). EGNOS was developed to address the rigorous requirements of safety-of-life applications. Key among those user requirements has been the aviation community, whose requirements are among the most demanding.
See: http://ec.europa.eu/enterprise/policies/satnav/egnos/files/combined-waas-egnos_en.pdf)

EGNOS has been operational and available for use as an Open Service since 2009, and is freely available to the public. The Commercial Data Distribution Service (CDDS) for customers who require enhanced performance for commercial use has been provided since April 2010. In addition, the Safety of Life Service (SoL), that provides the stringent level of signal-in-space performance to all communities of SoL users over Europe commenced in 2011 (European Geostationary Navigation Overlay Service, Accessed 2/18/15).

EUPOS

The European Position Determination System (EUPOS) is an initiative aiming to establish a uniform Differential GNSS (DGNSS) infrastructure in Central and Eastern European countries. Uniform multifunctional DGNSS reference stations and services will be built up in fourteen participating European countries. EUPOS is a partnership of public administrations and institutes working in the field of geographic information, land surveying and geodetic survey. These public organizations have already made a substantial effort to bring together experts which are willing to considerably extend the scope of

EUPOS plans to establish in total up to 870 reference stations in the thirteen member countries beyond Germany[11]. Since Germany has a complete network of reference stations (SAPOS), their financial support will be used primarily for international co-ordination, organization, supervising and promotion of the Project. Germany has but three stations in its territory.

The current EUPOS Station Database lists the following reference stations contributions: Germany 3 (Berlin), Bulgaria 8, Czech Republic 26, Estonia 9, Georgia 19, Hungary 34, Latvia 29, Lithuania 26, Macedonia 14, Poland 92, Serbia 28, Slovakia 29, Slovenia 14, and Ukraine 8, and the EUPOS network will include about 870 reference stations. The number of stations in Russia could not be determined from the information available (EUPOS, Accessed 2/18/15).

EUPOS objectives are (Rosenthal, 2008):

- EUPOS consists in establishing in Central and Eastern Europe a network of multi-functional DGNSS reference stations providing signals that could be used for both land, marine and air navigation and for geodetic point positioning;
- EUPOS reference stations will provide DGNSS correction data for real time positioning and navigation and observation data for geodetic post processing;
- EUPOS will fulfil all accuracy requirements of geodesy and navigation - centimetre and sub-centimetre in post-processing and centimetre as well, sub-metre and metre in real time mode;
- EUPOS will guarantee availability and quality of service continuity;
- EUPOS will use all satellite infrastructures existing or developing in participating countries and will use uniform technical standards based mainly on the German Satellite Positioning System SAPOS;
- As soon as the Galileo system is fully available, it will be the main standard for EUPOS.
- EUPOS will be independent from private company solutions and will use only international standards and additional worldwide unlimited usable standards.

European Plate Observing System (EPOS)

The European Plate Observing System (EPOS) is a long-term integration plan of national initiatives related to solid Earth Sciences research, and has been endorsed by the European Strategy Forum on Research Infrastructures (ESFRI) and included in the ESFRI Roadmap in December 2008.

[11] The 14 European countries participating in the Project are Bosnia and Herzegovina, Bulgaria, Czech Republic, Estonia, Germany, Hungary, Macedonia (FYROM), Latvia, Lithuania, Poland, Romania, Russian Federation, Serbia and Montenegro, Slovak Republic and Slovenia.

The goal of EPOS is to promote and make possible innovative approaches for a better understanding of the physical processes controlling earthquakes, volcanic eruptions, unrest episodes and tsunamis as well as those driving tectonics and Earth surface dynamics. Integration of the existing national and trans-national programs should increase access and use of the multidisciplinary data recorded by the solid Earth monitoring networks, acquired in laboratory experiments and from numerical simulations. EPOS will also foster worldwide interoperability in Earth Sciences and provide services to a broader community of users (EPOS, Accessed 2/16/15).

EPOS consists of European and Mediterranean countries, is such areas as:

- Geoscience data providers.
- Scientific user community (including Academia).
- National research organizations & funding agencies.
- Data and services providers and users outside the research community (including industry).

Several thousand researchers in Earth sciences should benefit from the services provided by EPOS, fostering major advances in the understanding of the processes occurring in the dynamic Earth, and is the European equivalent to the US PBO. The primary investments are from individual countries.

5.3.3. Russia

Introduction

In 1939 Sir Winston Churchill said "I cannot forecast to you the action of Russia. It is a riddle wrapped in a mystery inside an enigma; but perhaps there is a key. That key is Russian national interest." (Churchill, 1939) In this study Russia has remained an enigma and the cause would seem no different than what was explained 75 years ago. Obtaining hard information on highly technical, dual use (i.e. military as well as civilian) government systems has been a challenge. Nevertheless, given the scale of Russia's contribution to GNSS, any report of this type would be incomplete without at least a "best effort."

The GLObalnaya NAvigatsionnaya Sputnikovaya Sistema (GLONASS) of the Russian Federation, was the second operational GNSS network after the USA's GPS. Russia has invested at least the equivalent of US $4 billion by 2011, and is estimated to increase to a total of US$15 billion by 2020.

GNSS Science and Applications Development

Russia has made significant, long term investments and progress with their national GNSS infrastructure, and supporting science and applications. There are 24 Russian Federation sites listed as contributing to the International GNSS Service (IGS); a global foundation network of over hundreds of permanent, continuously operating, geodetic quality stations tracking GPS, GLONASS, Galileo, BeiDou, QZSS, and SBAS (International IGS Network, Accessed 02/17/15)

From a list that appeared on Git Hub, there appear to be 608 Continuously Operating Reference Stations (CORS) being operated in Russia. However, it is difficult to verify that we have interpreted the file correctly (GIT Hub, Accessed 2/17/15). The degree to which augmented GNSS is being used in Russia remains largely unknown: we have found no easily accessible published sources.

Finally, there are 14 GLONASS monitoring stations in Russia, as well as others in Brazil and Antarctica at Russia's Bellingshausen station, according to Russian officials. Additional foreign GLONASS monitoring stations are anticipated in Brazil and Antarctica, as well as Australia, Cuba, Indonesia, Spain, and Vietnam. Evidence for Russian international science leadership in GNSS can be seen by the scale of the forthcoming 2015 UN/Russia GNSS workshop on the civilian applications. There are several objectives of the Workshop. The first is to strengthen regional information and data exchange networks on the use of GNSS technology, including various training programmes and capacity-building needs in GNSS and its applications. A second objective is to develop a regional plan that would contribute to the wider use of multi-constellation GNSS and its applications, including the possibility of one or more national or regional pilot projects in which interested institutions could incorporate the use of GNSS/GLONASS technology. Lastly, the workshop is expected to make recommendations to the ICG (United Nations, Accessed 02/17/15).

GNSS Commercial Applications

Like GPS, the GLONASS system was originally intended for military application and its transition to commercial use began slowly. Its commercialization in general, but especially the development of the user segment, was initially lacking compared to the USA's GPS system. To improve the situation, the Russian government began actively promoting GLONASS for civilian use. For example, in 2001, the government announced that all passenger cars, large transport vehicles and vehicles transporting dangerous materials were required to use GLONASS-equipped navigators. The tracking of this road traffic will be tied to road tax collection as well as to a roadside assistance in the event of an accident. It is not believed that augmented GNSS is being used in this application (Anon, 2011). In addition, the government has been pushing for all car manufacturers in Russia to make cars with GLONASS since 2011.

The availability of GLONASS signals resulted in commercial gains that include:

- Qualcomm announcing the first GLONASS capable phone (MTS 945 from ZTE);
- ST-Ericsson launching "the world's smallest receiver" tracking both GPS and GLONASS satellites;
- Broadcom Corporation announcing two new GPS/GLONASS system-on-a-chip;
- Sweden's GNSS augmentation network SWEPOS deploying GPS+GLONASS receivers to benefit from the marginal benefit they offer at northern latitudes(Navipedia, Accessed 02/17/15).

So while the first real GLONASS capable civilian devices appeared only at the end of 2009, the technology quickly proved to be commercially viable. In 2011, navigation operator NIS GLONASS reported 3.3 billion rubles ($110 million) in revenues – 4.5 times more than in 2010 (Kramnik, 2012).

Political Challenges

Further growth is anticipated in the global markets for civil and commercial exploitation of GLONASS, although Russian economic contraction following the recent collapse of oil prices may result in significant Russian Government spending cuts. The major drop in the value of the Ruble further reduced Russian ability to purchase foreign component parts.

In addition, recent western economic sanctions have resulted in Russia deciding to continue to produce and launch nine of its existing class of GLONASS-K1 satellites rather than move to the advanced GLONASS-K2. (GPS World Staff, 2014) In parallel to this, the US Congress and Senate voted to prevent the Russian proposal for GLONASS monitoring stations to be established in the US, despite it being favorably viewed by NASA and the Federal Aviation Administration, which were interested in acting as hosts (Divis, 2014).

In summary, Russia is a major player in global GNSS, but may have challenges maintaining even current relative levels of sophistication compared to foreign systems.

5.4. Asia-Pacific

5.4.1. Introduction and Overview

As with Europe and North America, most countries are using GNSS Augmentation for some aspect of their aviation industry. This is especially so for countries like Thailand, India, China, Japan, Korea and Australia with well-developed hubs for international carriers. But otherwise, Asia is both more fragmented and more complex than either Europe or North America. It is much bigger in terms of land area, areas of ocean for which countries are responsible, and the number of disputes about who is responsible for what areas. In addition, Asia has more population, greater environmental issues, more severe natural disasters, and, in the end, a greater need for GNSS as well as GNSS augmentation services. This need has resulted in a number of market studies suggesting that there will be significant growth in Asia in the use of GNSS over the next few years (Frost and Sullivan, 2012; European GNSS Agency 2013). It can be expected that there will also be a growing demand for GNSS augmentation services, here regarded as a subset of the GNSS market.

Recognizing this fragmentation and the potential value of an Asian Space Agency modeled after ESA, the UN engaged a senior level consulting team in 1996 to explore the idea and develop a framework to discuss at a regional UN-ESCAP meeting. The concept was supported by China and Japanese industry, but the Asia-Pacific region was too fragmented, with three major players (China, Japan, and India) not prepared to work together in such a sensitive area (and not always looked on favorably by a number of the smaller players, of whom there are many). Australia and New Zealand presented other problems at the time.

There has been an attempt to create an organization to "promote multi-GNSS utilization and applications in the Asia and Oceania region" called Multi-GNSS. (Accessed 2/10/15) It was spearheaded by JAXA, the Japanese Space Agency. The most recent workshop, sponsored by JAXA, the United Nations International Committee on GNSS (UN ICG), the EU and several commercial entities, was held in Phuket, Thailand in October 2014. It attracted 100 participants from 14 countries, including four speakers from Europe. The assumed ten participants from the Asia Pacific Region represent less than 15% of the region's countries. According to the organization's web page only 11 countries are represented in the membership, although all of the key countries in the region are engaged.

Adding to the complexity are the widely varying levels and rates of development. All but a few countries are less well developed than those in North America and Europe. Adding to the problem is a lack of sophistication in some of the main areas of application in much (but not all) of the region. In the case of agriculture, for example, most fields are far too small and with a few exceptions mechanization is limited compared to North America and Europe. Malaysia, one of the countries higher on the development scale, is using GNSS technology, as is Japan and both Australia and New Zealand. In the case of mining in the Asia-Pacific region, rules are often quite different or differently applied compared to Europe and North America. Precision is not always needed and, except in a few notable exceptions (such as Australia), machine guidance has not yet caught on across the region.

In addition to the use of GNSS augmentation in support of air traffic, there is one other similarity with the other regions: the service industry is active – sometimes in a Public Private Partnership role related to land survey, land tenure, and/or taxes. One such example sees Leica working with other commercial players in the Philippines, where they installed 13 active control stations (Gatchalian, 2011 the public private partnership concept was also presented in March 2014 to the World Bank Conference on Poverty and Land Tenure). Showing sensitivity to its clients, Leica has web pages in most of the major languages of Asia and Europe.

The major markets for GNSS in Asia were identified in the 2012 Frost and Sullivan (2012) as being India, China, Taiwan, Korea and Japan. The European GSA (for whom Frost and Sullivan did the report) now focuses on these markets for Galileo.

Obviously Japan, China, and India, each with a GNSS satellite program, are important to understand the Asian situation and each is considered separately in the following Sub-sections. After these, Australia provides another view relevant to Canada. A number of other countries are profiled in Appendix D to show the range of augmented GNSS use, and, in some cases, the slowness of its adoption.

5.4.2. Asia-Pacific Country Profiles

Japan

Japan was an early player in the GNSS field and in GNSS augmentation as well. While government has played a dominant role, Japan's involvement in GNSS has been strictly civilian, as would be expected given its post-war constitution. Japan began to install GPS/GNSS reference stations in 1992 and, over the years, has purchased over 2700 stations including modernization or replacement of early stations. (Trimble 2012) According to the US government (Accessed 2/10/15) "The United States and Japan have enjoyed a successful relationship on satellite navigation since 1998, when the heads of both nations signed a Joint Statement establishing cooperation in the use of GPS. Through this relationship, the two nations have achieved interoperability between WAAS and Japan's MTSAT-based Satellite Augmentation System (MSAS). The nations have also taken steps to ensure interoperability between the next-generation GPS constellation and Japan's Quasi-Zenith Satellite System (QZSS), a regional satellite constellation designed to complement GPS over East Asia."

The QZSS (nicknamed Michibiki) is expected to be working by 2018 with four satellites providing GNSS corrections in support of seismic studies, land survey, logistics, machine guidance (including precision agriculture) and transportation. Accuracies are expected to be on the order of several decimeters – not as precise as can be obtained from the best performing PPP services or RTK networks.

In 2012 the Geospatial Information Authority of Japan (GSI) bought 500 GNSS receivers to modernize the CORS of its nationwide GeoNet network. (Trimble, 2012) As mentioned above, GNSS augmented data of the sort provided by the CORS stations have been used by Murai and his team to apparently predict (after the fact) earthquakes. More traditional current uses for augmented GNSS in Japan include land survey, precision agriculture, aero surveillance, construction, logistics, traffic, security, and environmental protection. Japan's expertise in robotics has led to some interesting research that involves precise location.

While JAXA has attempted to develop a regional organization, the take-up does not seem to have been very large beyond the usual players – Australia, China, India, Japan, Malaysia, South Korea, and Taiwan. When one considers discussions on boundaries in the region, it is not surprising that agencies or companies from the Philippines, Vietnam and Brunei are involved under Japan's leadership. Singapore is also involved.

China

The first thing to understand about China in the GNSS context is that it has a long and proud history in mapping and navigation, a history that is referred to in almost every presentation on the subjects of mapping, remote sensing and positioning by Chinese scientists. The first compass was developed in China around 300 BC, and topographic maps were first made in China in 168 BC. The compass was used on ships in China over 1000 years ago, some 200 years before they were first reported to have been used in Europe. China's renewed interest in remote sensing, space, and elements of navigation began in the 1980s under Deng Xiaoping who is rumoured to have been the mentor to several well-known specialists in these fields. In his first visit to the USA, one of the places Deng visited was the Johnson Spacecraft

Centre. That visit was consistent with the fact that space, mapping and remote sensing were always accorded an important place in the five year plans beginning in the 1980s. China was the first country to make land use maps of the entire country using satellite remote sensing: the agency responsible, the State Bureau for Surveying and Mapping, is one of the founding partners involved in China's GNSS.

In 1994 China began development of their demonstration satellite navigation system called Compass or BeiDou, with the first satellite launched in 2000. (Chinese navigators followed the Big Dipper, or BeiDou in Mandarin – hence the name for the navigation satellite system.) As recently as late-2006 the Chinese satellite system was expected to remain a regional system inasmuch as China was investing $290M in Galileo based on a 2003 agreement. At the time it was assumed that China's satellite would remain solely for the use of the military. But in 2006 China announced that BeiDou would become a global system that would work in concert with other systems. This may have been a response to military concerns about protecting sea routes for China's growing reliance on international trade. Gibbons (2008) provides a concise rational for interest in China's use of GNSS: "As a GNSS player, China arouses interest and concern on at least four levels: as a service provider (compatible or incompatible), as an equipment manufacturer (competitor or partner) as a product designer and technology distributor (re-engineering or innovation), and as an enormous market or untapped potential (open or closed). Some of these concerns have become a reality, as the CORS market in China, discussed below, suggests.

By October 2012, 16 satellites had been launched and became operational by the end of December. Details of the civilian system were published to allow manufacturers to build receivers that could use its signals. In May 2014 China and the USA announced a joint statement on a number of topics including "compatibility and interoperability of civil signals between BeiDou and GPS, their respective augmentation systems and civil aviation applications" (US Government, Accessed 2/10/15). In the official description of the BeiDou satellite system it is interesting to note that the first objective stated is to "meet the needs of China's national security." That is followed by "economic development," and "technological advances" (China Satellite Navigation Office, 2013). It is expected that full world-wide service will be operational in 2020[12]. It has been reported that there are two levels of service provided; a free service to civilians and licensed service to the Chinese government and military. The free civilian service has a 10-meter location-tracking accuracy, synchronizes clocks with an accuracy of 10 nanoseconds, and measures speeds to within 0.2 m/s. The restricted military service has a location accuracy of 10 centimeters, can be used for communication, and will supply information about the system status to the user. To date, the military service has been granted only to the People's Liberation Army and to the Military of Pakistan.

A number of companies have been supplying CORS stations in China. In 2009, following the massive earthquake Trimble sold 295 CORS stations to monitor crustal deformation. TopCon provided a further 132 stations (Inside GNSS, 2009). A Chinese company, Hi-Target, established in 1999, focuses on the GNSS market. The company reported sales of $45.75M for the most recent year (Hi-Target, Accessed 2/8/15). They state that they have sold 300 base stations in China – almost half of the CORS stations. As Gibbons suggested above, China has become both a market and a competitor.

As is the case elsewhere in Asia, the range of application is far greater in the less precise areas of GNSS application, ranging from transportation navigation to fisheries, vessel location, and the like. However, the range of applications of augmented GNSS in China is significant and growing. The damage caused by earthquakes has made crustal movement and disaster mitigation important areas of focus, although available material suggests that the range and depth of use do not quite match those in Japan. The use of

[12] This information and what follows in this paragraph has been drawn from Wikipedia, citing sources published in China in Mandarin. http://en.wikipedia.org/wiki/BeiDou_Navigation_Satellite_System

the satellites for communication for forest fire prevention and real-time distribution of hydrological monitoring for flood forecasting have been tested with some success. The use of augmented GNSS for land survey and precise location has been an important application during the rapid growth of both inter- and intra-urban infrastructure and transportation.

India

India has a long and distinguished history in space. The importance accorded the space program can be seen from it being at a Ministry level. Not only is there a Deputy Minister level individual responsible for Space (the Chairman is now Dr. K. Radhakrishnan, who came up through remote sensing), it is the only government organization at that level not headquartered in New Delhi.

India has long had ambitions to develop its capacity as a GNSS provider. The India Space Research Organisation (ISRO) is responsible for these activities and all systems are entirely controlled by the government for security reasons, as explained below. There are two existing national systems that are relevant: the GPS Aided GEO Augmented Navigation (GAGAN) program and the Indian Regional Navigational Satellite System (IRNSS).

The GPS Aided GEO Augmented Navigation (GAGAN) is an initiative to establish a satellite-based augmentation system over Indian (and adjacent) airspace for improved air traffic safety. This is a joint program between the Airports Authority of India and Indian Space Research Organization, with some of the key technology coming in part from Raytheon – which supplied the technology for similar systems elsewhere. GAGAN was declared operational in early 2014. With this, the country has become the fourth to offer safety of life, space-based satellite navigation services to the aviation sector. GAGAN will provide augmentation service for GPS over the country, Bay of Bengal, South East Asia and Middle East expanding up to Africa. The GAGAN system will bridge the gap between European Union's European Geostationary Navigation Overlay Service (EGNOS) and Japan's Multi-functional Satellite Augmentation System (MSAS) coverage areas. The benefits of GAGAN include improved efficiency, direct routes, increased fuel savings, approach with vertical guidance at runways, significant cost savings due to withdrawal of ground aids and reduced workload of flight crew and Air Traffic Controllers (Radhakrishnan[13], 2014).

The Indian Regional Navigational Satellite System (IRNSS) is an autonomous regional satellite navigation system being developed by ISRO which is under total control of the Indian government. This matter of control is an important point. It was reported that it was the inability of India to obtain GPS data during a conflict in 1999 that led to the decision to invest in a secure, Indian controlled system. The system will allow India to "keep a close watch of not just its boundaries, but up to 1,500km beyond" (Srivastava, 2014). By mid-year 2015, the entire set of seven geostationary satellites should be in place. The concern for security will see civilian use of 20 meter accuracy, while the military will have access to 10 meter accuracy. In all of the material reviewed for this report, the only direct quote of any senior official referring to weapons was with regard to this system when Mr. Ramakrishnan, Director of the Vikram Sarabhai Space Centre was quoted as saying: "Many weapon systems like guided missiles and bombs also use such navigation systems. An indigenous system allows the development of such capabilities in a reliable manner. There is also the need to have your own navigation system in the civilian and commercial domain since so many critical services and businesses depend on it. A system run by another country (like GPS) may be switched off in times of crisis leading to complete collapse of certain services" (Srivastava, 2014).

[13] This Radhakrishnan is a journalist, not the Secretary of Space.

While there is great interest in India by the EU in terms of business to business cooperation on the technology side (both hardware and software), and while there has been an assessment of the potential market, there is very little readily available recent information available on the uses of GNSS in the country, never mind augmented GNSS. The primary interest some years ago related to location based services using more general GNSS position information. Uses included fleet management, transportation management, ambulance service, police, towing, taxi, and hospitality services and booking. However, the report was short on specifics. The areas of potential business identified at a UNOOSA meeting in 2007 (Kaushal, 2007) were: Defense; Transport; Crime (Police); Health (Ambulances); Municipalities (Garbage dump vehicles, Asset Management, Property taxation); Utilities (data collection, fault detection); Environment (trees and their location/identification); National parks (movement of wild animals); Advertising (location of sign boards); and Automobiles (navigation, thefts, breakdown, accidents, drivers performance).

It is interesting to compare the view in 2007 with the EU's market study believed to have been conducted in 2012 or 2013 (European Union GNSS Agency, Accessed 2/10/15). The EU study suggested that there may be opportunities for the GAGAN system in maritime operations, in surveying and some areas of research. One could presume the same for the Indian Regional Navigational Satellite System (IRNSS). Surveying does have some promise, but to date the Survey of India has not responded to our request for information. In many other areas such as vehicle navigation and fleet management it was suggested that poor infrastructure and poor access to supporting information would limit the use. While an urgent need was identified for automation in the railways in traffic management, goods tracking and passenger information, again there are issues with infrastructure. There was also a belief that there will be "humongous growth" in the geospatial market in health, government, logistics, agriculture, telecommunications, utilities, environmental management, forestry and infrastructure. While a more open data policy will help in this regard, it is believed that even today, two years after the study was done, the realization of benefits is still some years away. The same can be said for the location based services industry – the market may be huge ($20 billion was the estimate of the potential market), but the supporting map and other data are simply not yet available. One area where augmented GPS may play a role is in precision agriculture where the belief is that there will be "wide spread use in the future." Again, the infrastructure to make this a reality is far from ready.

India is making advances in the technology area, will have operational systems in place, but appears to lack the infrastructure and inclination to make use of either GNSS or augmented GNSS services. In one sense this mirrors the situation one found when India began launching remote sensing satellites: the satellites were launched before the infrastructure was in place to effectively use the data. However, a system of regional facilities was developed to foster the use of the remote sensing data and the data was quickly taken up in a number of user communities. The individual in charge of developing that system to foster the use of that data (and who earned a PhD in industrial engineering from the Indian Institute of Technology for having done so) is now the head of ISRO. If one can expect that the same attention to proving the utility of the data will develop, the bright future may well unfold – but all evidence suggests that it will take some years to do so.

Australia

Australia is an interesting case, given that there are a number of similarities between Australia and Canada. Both are resource-based with the bulk of the population located in a narrow band on the periphery of the country with large areas virtually unpopulated. They share a similar political system, linguistic heritage, similar level of development, and both face significant impacts projected from climate change. There are two major differences: as Australians will be quick to say, we in Canada are close to the USA market and, in terms of GNSS, we are under the USA's umbrella with ready access to technology, advice and partnerships. However, Australia also has partnerships with the USA in GNSS but, because of its relative isolation, it has also had to come to rely on Japan's Multi-functional Satellite Augmentation Service, as Canada does with WAAS.

Given these similarities, how Australia deals with at least certain aspects of GNSS augmentation is instructive. Australia has not only been using GNSS augmentation services as has been well documented elsewhere in this report: as noted above, it has carried out an assessment of GNSS's impact on the economy and clearly understands the technology's value (ACIL Allen, 2013). The fact that it could rapidly assemble a response to our questions is yet another indication that the activity is well managed, well understood by management, and well supported by coherent long term planning. The full report provided by Geoscience Australia is reproduced in Appendix A. The Australian National Positioning Infrastructure (NPI) Policy and Plan are introduced at the top of page 5 of the Australian material in Appendix B.

The succinct summary on page 5 of Appendix B is important and recommended reading.

The recently established NPI Advisory Board is a model that Canada might consider for an external advisory board. It is instructive that the Advisory Board is now involved in the development of a strategic plan. This sequence of an economic or benefits study, engagement of an external advisory body and formulation of a strategic plan follows the logical approach to strategic planning in geospatial that we have used in Thailand, Bermuda, the Maldives and Canada (Ryerson and Peanvijarnpong, 2007; Atwood et al, 2009; Shafee et al, 2010).

Australia's success seems to be associated with clearly understanding and communicating the value of GNSS and explaining the technology in language that is easily understood by policy makers. This emphasis on demonstrating value in its geospatial activities can in part be attributed to Australia's relatively well coordinated geospatial activities under the auspices of the government, including the Australia and New Zealand Cooperative Research Centre for Spatial Information which has funded a number of the major economic studies. Australia has used this knowledge and expertise to contribute to expanding the Australian voice in international organizations and in the development of exports of services. Virtually every international conference and working group in the field seems to have Australian representatives, or Australia provides the "pen" or secretariat. This is so for the UN Panel of Geospatial chaired by Vanessa Lawrence, the Asian Association on Remote Sensing, and the World Bank. For example, one of the senior officials at the World Bank in the area of land survey is Keith Clifford Bell, former Surveyor General of Victoria State. This approach to using technical expertise to develop international influence (and ultimately exports) is not unlike the approach used in Canada's remote sensing program some years ago.

The role that Geoscience Australia sees for government is also instructive. They are not unlike what people whose ideas and opinions were solicited for this report have said. Furthermore, the perceived role seems to mesh well with the attitudes of the Government of Canada in terms of supporting the development of infrastructure, economic development, and industry. As the strategic plan unfolds, it can be expected that there may be changes in the perceived role, but for now, the list may be a useful departure point for Canada's consideration. "The future role of the Australian Government in the precise positioning domain is viewed by GA as follows:

- Build and operate the primary ground network needed to track multi-GNSS signals;
- Develop multi-GNSS products and services (e.g. precise satellite orbits and clocks) that are optimised for Australia;
- Establish the NPI as a base-level positioning capability that is fit-for-purpose for positioning applications deemed critical in the national interest (e.g. transport);

- Develop the capability to deliver data from the NPI via ground and satellite communications (e.g. by leveraging SBAS and other multi-GNSS capabilities);
- Enforce ground infrastructure and data standards based on international best practice;
- Provide legal traceability of position;
- Develop and operate the capability to monitor and report on the performance and integrity of multiple satellite positioning systems;
- Strengthen partnerships with the international positioning community to link and align public infrastructure and services with international campaigns;
- Encourage industry champions" (Personal Communication, John Dawson, 2/19/15).

The role seen for industry is also clearly stated on the last page of Appendix B and that role is also consistent with the Government of Canada's stated policies on how industry and government activities mesh.

Geoscience Australia provided the cost figures in Table 3 and have estimated that the 130 stations in the Australian network cost $19.5 million (AUS$) to install with an annual operating cost of $650,000. The operating costs are shared with state governments. Complete details are provided in Appendix B.

5.5. Conclusion: Regional Comparison

This section with the additional material in Appendix D has shown that the main points of difference in GNSS augmentation uses and the role of government in North America, Europe and the Asia-Pacific Region are related to:

- When the technology was first embraced;
- The support of government;
- Varying levels of development;
- The level of fragmentation between the countries in the region;
- Level of investment of individual countries
- The number of major countries in the region and their relative strength;
- The level of apparent trust between countries;
- The perceived role of the military; and
- The role seen for local industry.

Table 8 provides a convenient means to show the similarities and differences between the three regions.

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Table 8: Comparison Between North America, Europe and Asia-Pacific in GNSS Augmentation			
Comparative Point	**North America**	**Europe (Includes Russia)**	**Asia-Pacific**
Number of Operational Satellite Systems Today	1	2	2 (Japan, China)
Number of Operational Satellite Systems Planned	0	0	2 (Japan and India)
Number of global supplier companies based in the region	2 (Trimble and John Deere)	3 (Hexagon owns several companies; Fugro owns one)	2? (TopCon - Japanese) Hi-Target?
Degree of Fragmentation Between countries - Rank	1 (Very low)	2 (Medium)	3 (Very high)
Number of major countries or blocks of countries	1	2 (EU and Russia)	3 (China, Japan, India)
Level of Development - Rank	1 (High)	2 (Medium to high)	3 (High to low)
Uses in land survey	Yes	Yes	Limited – growing fast
Degree of govt control over access (beyond controlling rogue state access)	Low	Medium	Mostly high
Clearly stated military involvement in satellite control	High	Zero	Zero to very high
Military involvement in CORS station control and access	Low	Low	Zero to High
Potential importance of use re natural disasters	Medium	Low to medium	High
Projected growth in market compared to other regions	Low	Low to Medium	High
Government supplemental service available	WAAS	EGNOS (European Geostationary Navigation Overlay Service)	Japan's Multi-functional Satellite Augmentation Service
Active in FIG	Yes	Yes	Yes, but variable
Who provides training related to GNSS augmentation	Industry, Academe	Industry, Academe, government	Industry, Academe, Government
Strong, internationally accessible educational research opportunities	Yes	Yes (EU)	Limited (Australia, Japan)
Regional GNSS Body	No	Yes	No
Active in International Committee on Global Navigation Satellite Systems (ICG),	US	EU, ESA, Russia, Italy	China, India, Japan, Malaysia
Information on use readily accessible	Yes	Variable – No to Yes	Variable – Mostly No (except Australia)
Overall degree of govt involvement and control	Low	Medium	High

6. Trends in GNSS Augmentation

6.1. Introduction

One of the most interesting aspects of this study has been speaking with a number of people involved in the field and reviewing the technical literature and various newsletters with the goal of identifying trends and what the future holds in terms of changes in applications, technology, the role of government, the role of industry, policy changes, and the like. The trends outlined here are ones that have been identified to the authors of this report, as well as a number that have come from a rapid review of the literature. In addition, we have identified a number of what we refer to as underlying factors that one can say "inform" the trends or provide the context in which trends can be better understood. This section begins with an outline of several underlying factors and then presents the identified trends.

6.2. Underlying Factors

There are a number of underlying factors that we believe affect the trends in GNSS Augmentation. These can be categorized as social and technological.

The first social factor is the so-called "addiction to accuracy." The first mention of this "addiction" was found, not surprisingly, in a reference to GPS (***Economist Technology Quarterly,*** 2002). References to GPS and/or locating one's position on Earth have appeared in virtually every technology review done by the ***Economist*** ever since. Simply stated, the more accuracy one has access to, the more accuracy one wants. Like an addiction, very soon the "want" becomes an on-going requirement. Furthermore, as the "addiction" grows and accuracy improves, more and more uses are developed that were never previously considered. This was well said in the Economist in 2002: "Already the basis of a $12 billion global industry, GPS is an example of a self-perpetuating innovation: the better it gets, the more uses people find for it." Some of these new uses have been obvious – the use of GNSS to steer farm equipment and control application of chemicals to crops, for example. The first unexpected use (and the ultimate social application) saw GPS enabled cell phones used by Japanese teens to locate their friends on a Friday night in the Ginza area of Tokyo. The social and business implications of this use in Japan are significant (Warner, 2003).

The next social aspect is the growing importance of the consumer market. Those who ignore the consumer market do so at their peril – as Blackberry found out. Positioning to 1 meter accuracy has arrived in the consumer's hands. It didn't take much intellectual effort to move from using GPS to navigate streets and farmer's fields to navigating golf courses using more precise (1 meter) location information. But who would have thought that satellite imagery, maps, and positioning technology would be linked to advertising to build one of the most valuable companies on Earth? Precise positioning technology has now well and truly entered the consumer market. Counting a cell phone, this author has four hand-held consumer-oriented GPS devices with 1 meter accuracy.

When looking at social factors underlying trends it is useful to differentiate between commercialization of a technology and monetization. Commercialization is the process of introducing a new product or production method into the market. Monetization turns an asset into money. Typically commercialization is done following a set of steps – moving from a laboratory into a beta test and then into a commercial product that was likely seen as the end-game early on in the process. Monetization tends to be more disruptive and less predictable. As the use of any technology enters the mainstream consumer market, there will be entrepreneurs who will see a way to monetize the technology and its use. Google is but the best known case. GNSS Augmentation has already entered into this phase. The same minds that built Google are now examining how more precise positioning can be used to better serve clients and enter new markets. Amazon has experimented with Un-manned Aerial Vehicles (UAVs) to deliver packages. Some have said that this is a publicity stunt…others see it as a potential game changer or disruptive technology for the delivery business.

Another "social" factor is the growing interest in serving isolated areas of the world for resource development and other needs. Precise point positioning is the only technology that can easily and readily serve such isolated areas' need for accurate position information – be it for navigation, precise location of a sample plot to which one wishes to return, or the measurement of a changing glacier or water body.[14]

The last underlying social factor is that of trust. In a previous study we found that a significant percentage of several hundred respondents trusted geospatial data that was approved by the government, but did not trust data provided by the private sector (Ryerson et al, 2009). Trust is an important issue given the incredibly high value of decisions being made based on GNSS augmented data.

There are several technological factors that affect trends in GNSS Augmentation. We have said elsewhere that access to better tools will help humanity escape the "tyranny of our geography" (Ryerson and Aronoff, 2010). The power and complexity of hand held devices is increasing just as smart phones have become a commodity. At the same time, the computing power in hand held devices continues to grow, as is the ability to both send and receive large amounts of information by cell phones. Location is in everyone's hands – or at least for everyone who has either a cell-phone and/or advanced GNSS PPP compatible receiver. The cell phone has already changed banking in Africa and India, among other places. Money can "change hands" without ever going near a formal bank. A recent cover of Bloomberg Business Week depicts the death of the wallet – it will be replaced by a mobile device. Mobile devices are more powerful than ever: simple and light weight technology allows us to determine our position with unprecedented accuracy. Where might this convergence of technologies and societal needs take us? What new sectors will emerge?

One fundamental conclusion is that within the next five to ten years uses of augmented GNSS that have not yet been widely considered will be among those that the industry will be promoting – and that will be making more people rich.

With these underlying factors and the inventiveness of the marketplace, we can expect new opportunities to continue to arise. This has been confirmed by the responses to our interviews and questions.

6.3. Future Trends in GNSS Augmentation

The trends seen by the players in the market are, to some extent at least, somewhat predictable given by their pedigrees. The commercial players in GNSS have come from several different directions and backgrounds. Trimble and TopCon have long served the land survey business and their presence as GNSS augmentation service providers could have been predicted. Leica had some of the same roots, as did NovAtel. Both are now owned by Hexagon, the large Swedish engineering company that has bought a number of companies involved in the geospatial realm: they see location information as a fundamental building block of the economy. John Deere has come from the farm equipment world: GPS enabled farm equipment was seen as a means of differentiating themselves from competitors and placing them as a high end supplier. Fugro has long served the mineral and oil exploration market and they too saw a need in their market and have moved into the field. CanNet has a background in land survey but have moved into

[14] In the development context the use of PPP meaning Precise Point Positioning should be discouraged: in international development the term means Public Private Partnership.

agriculture. Each company brought a different strength and now they are all competing to one degree or another in much the same market space.

A viewpoint held by several of those who provided input is that the GNSS equipment vendors will continue to lead the way in precise positioning technology (e.g. Trimble, Leica, TopCon, etc). Users will demand more accurate positioning and quicker results (real-time) world-wide.

The following have been suggested as trends or "things to look for" in the future:

- Hand held mobile devices will be more powerful and will assume more of the work load;
- The next fifteen years will see a maturing of the market for augmented GNSS services with higher penetration in areas where it is now used;
- Use of augmented GNSS services will increase in areas where it is today weak, notably in developing countries;
- There will be more recreational use;
- Costs will go down;
- More income will come from subscriptions;
- Consumers will begin to buy services – or get access on some "Google-like model" – i.e. a third party will pay for access based on a different monetization scheme;
- There is some (muted) concern about the GPS system being kept up;
- Governments (states in the USA) will stop operating RTK networks in competition with industry;
- Governments' role will continue to be important for the foreseeable future:
  - Governments will provide the space component. Only governments will have the resources and desire to launch, maintain and improve GNSS satellite constellations. This is the infrastructure that all users of GNSS depend upon, much like commerce depends on the maintenance of most roads and highways being done by government;
  - Governments will work in areas where there is no commercial interest (e.g. far north);
  - Government involvement (and ultimate control) will have to continue for security and public safety reasons – especially in Asia, areas not served by industry, and those areas prone to disasters such as earthquakes and flooding;
  - Governments will be the primary custodian, supporter, and protector of the infrastructure in the future, including providing control and confirming accuracy of the base upon which the entire system rests;
  - Even in areas where the private sector is providing ground infrastructure, Government will have to continue to provide a "bare bones" presence and expertise in the event of a cataclysmic disruption to the private sector network;
  - Governments in developed countries will continue to support GNSS augmented services in less developed countries; and
  - A more efficient method of implementing datum revisions is needed (resurveys and readjustments are expensive and time consuming).
- Precise Point Positioning will become more important;
- Cell phones and rovers will continue to be used;
- There will be better accuracy, improvements in reliability, and diversification of use – world-wide;
- GNSS use has grown exponentially in the last 25 years and use is now prevalent throughout many technologies and industries and has even become a critical part of many basic technology necessities. All other uses should (and in many places will) be market driven and guided, with minimal government intrusion, except where public welfare and safety are in question;
- Industry will (should?) work with government to protect the integrity of frequency spectrum, to ensure that improvements to the satellite infrastructure are planned, designed, funded, and implemented in a timely and fiscally prudent fashion;

- Increased adoption as performance increases while cost decreases;
- More countries will join the International Committee on Global Navigation Satellite Systems (ICG) and that Committee will be an even more important window on the field;
- Additional satellite systems plus GPS modernization should lead to improvements in satellite availability and accuracy;
- There will be a further blurring between geodetic applications, that is precise applications, and consumer applications, as the latter will be provided with more sophisticated options; and
- Sensor fusion will truly emerge – with GNSS, INS and vision-based sensors leading the way towards ubiquitous positioning.

7. Conclusion

The role of government has, in certain ways, continued on the same path as in the past, and has changed quite remarkably in other ways. Governments are the only ones building and financing the space component and governments continue to support basic geodetic research. That research is more likely to focus on a societal need (earthquake prediction, for example) rather than on more esoteric topics. There has been a useful lesson, however, in the area of geodesy. What began as esoteric research on movement of the earth's crust has, with augmented GNSS, led to a better understanding of earthquakes. Indeed, one Japanese scientist has claimed the ability to predict earthquakes using augmented GNSS data. Interestingly, he and his colleagues have formed a commercial entity to sell a service. Another area of research has come from the increased accuracy of GNSS augmented services: there has been significant research using more accurate data in all manner of research related to robotics, UAVs, the environment, and many other fields of endeavor.

It is also clear that governments have a role in providing the base or control on which the entire GNSS services business rests. This role of underpinning can be seen in the value placed on the Canadian Geodetic Survey by industry. This is in part related to the issue of trust: governments tend to be more trusted than private sector groups when it comes to geospatial information.

While the role of government in providing the space infrastructure continues, there are new models emerging for government involvement in the ground segment. These models vary considerably from country to country depending upon the country's geography, the stage of development and the degree to which the military or security forces control access to the information.

In some cases the bulk of the ground segment is still paid for and controlled by government. In some cases this is a hold-over from when the military controlled mapping or because of security and public safety concerns in the country. In the case of China and Japan, it may also be that governments are reluctant to put technology important for disaster response and mitigation into private sector hands. In less developed countries like Bangladesh, government is the sole provider of the ground segment (and a late provider at that) since there is virtually no private sector with the justifiable business case to support such services. In still other countries Public Private Partnerships are used – a justifiable business case has been developed. In the Philippines a private sector partner is engaged in land titling and derives income from providing a service in this domain.

In Canada, the USA and Australia the private sector provides a significant part of the ground infrastructure in the form of thousands of CORS stations. But in all three countries there are large swaths of the country where the private sector cannot justify the expense of supplying the ground infrastructure – there is no market for services. These areas must continue to be served by government. A case can also be made for the government to continue to provide a modicum of involvement in areas well-served by industry as a back-up and to provide control and a stabilizing influence. However, one might also argue that there is significant and perhaps needless overlap between government and private sector services in some parts of the USA.

The total investment of the government sector in Canada in augmented GNSS appears to have been about $ 32 million, including the projected Coast Guard investment, but excluding Nav Canada. The private service sector has invested about $20 million, not including PPP. These numbers do not include the many millions of dollars spent on the technologies needed to use the services – such as machine guidance systems on farm equipment or construction equipment, navigation systems on aircraft, or survey equipment. Given the economic impact of these technologies on Canada, never mind security and governance issues, this would appear to be an excellent and necessary investment of government resources. The investment in PPP world-wide has been roughly estimated to be on the order of $50 million.

As new technologies are developed, and prototypes are deployed, policy makers and regulators are increasingly left scrambling, making for a less than clear ten year horizon as to user demand for augmented GNSS services in transportation and other sectors. Will UAVs be approved for use in delivery? What are the insurance implications for autonomous vehicles? Will precision agriculture move into Asia? What role will augmented GNSS play in public safety? Will the technology lead to prediction of earthquakes? However, regardless of how these questions are answered, one thing is clear: the need will grow for trusted and authoritative augmentation systems delivering increasing horizontal and vertical resolutions with high reliability. This in turn will drive the need to monitor the integrity of such systems, a role that is typically seen to be the role of national governments.

The technology is changing rapidly and GNSS augmented services are growing in both their use and importance. Some governments are developing advisory structures, strategies and plans to ensure that their countries are able to both keep up with the technology and its application for the benefit of the people. Australia seems to be a useful model in that respect.

The final conclusion is that the Canadian government will have an important but ever changing role to play in Global Navigation Satellite Systems to ensure that:

- The safety and security of all Canadian's is assured:
- Our resources are properly monitored and managed; and
- Our industry can remain competitive in the many areas touched by GNSS augmented services.

Now would appear to be a good time to ensure that the advisory structures, strategies, and plans are in place to ensure that Canada benefits to the maximum extent possible from augmented Global Navigation Satellite System services.

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Appendices

Appendix A: Names and Affiliations of Individuals Interviewed or Who Responded to Requests for Information up to February 19, 2015[15]

1. Jonathan Ball, TopNet
2. Stephen M. Browne, Veripos
3. John Dawson, Geoscience Australia
4. John Festarini, Canadian Coast Guard
5. David Janssen, CanNet
6. Glen Mattioli, Plate Boundary Observatory
7. Lt. General David O'Blenis (Retired), aircraft owner.
8. John Pointon, Trimble Positioning Serves / OmniSTAR
9. Jean Sebastien, Leica SmartNet
10. Henry Wong, Metro Vancouver

[15] None of the organizations contacted in Europe responded to any of our requests for information or to the follow-up messages. The cut-off date was because the Draft Report was due February 23rd, 2015.

Appendix B: Geoscience Australia Summary

The material in this appendix was provided to the contractor, Kim Geomatics by Geoscience Australia. This was the only organization in the world that provided information by acquisition, processing and dissemination.

Australian Government

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Dr Bob Ryerson
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RE: Information request from Kim Geomatics on behalf Canadian Geodetic Survey (Natural Resources Canada)

19th February 2015

Dear Dr Ryerson

Geoscience Australia (GA) is pleased to make this submission in response to your request for information on Global Navigation Satellite System (GNSS) activities in Australia.

The following response has been prepared in-confidence to support your consultation on behalf of Canadian Geodetic Survey (CGS). GA has provided information on budgets, long-term planning, and the roles of government and industry in the precise positioning domain.

We trust this information will be useful and look forward to reviewing your findings.

Please contact Dr Grant Hausler (grant.hausler@ga.gov.au) if you require any further details.

Yours sincerely,

Dr John Dawson
A/g Group Leader
Geodesy and Seismic Monitoring
Geoscience Australia

Background

Geoscience Australia (GA) is the Australian Government agency responsible for national geodesy and civilian Positioning, Navigation & Timing (PNT). GA is the national focal point for coordination of geodetic information and data, working with state/territory agencies, the Intergovernmental Committee on Surveying and Mapping (ICSM) and industry groups to provide the best data possible.

GA cooperatively operates and maintains a Global Navigation Satellite System (GNSS) network comprising approximately 130 Continuously Operating Reference Stations (CORS) across the Australian and South Pacific regions. This network includes:

- The Australian Regional GNSS Network (ARGN)
- The South Pacific Regional GNSS Network (SPRGN)
- The AuScope Network

GNSS is only one component of the national geodesy program. GA operates two Satellite Laser Ranging (SLR) stations to facilitate satellite orbit determination and support estimation of the origin and scale of the International Terrestrial Reference Frame (ITRF). GA also operates three Very Long Baseline Interferometry (VLBI) facilities that support measurement of Earth rotation and orientation.

GA maintains the Geocentric Datum of Australia (GDA 1994) and manages related products and services for accessing the national datum and facilitating PNT across Australia and its maritime jurisdictions. These products and services include:

AUSPOS – a free online GPS processing facility provided by GA to post-process GPS data collected anywhere on Earth. Users submit their GPS data online and receive an AUSPOS report containing GDA94 and ITRF coordinates.

Regulation 13 Certificates - Regulation 13 Certificates are a legal document displaying a station coordinate and the uncertainty of that coordinate. These Certificates are generally requested by CORS operators as a means of providing users with an accurate connection to the Australian Datum (GDA94). GA is appointed as a legal metrology authority under the National Measurement Act 1960 to provide this legal chain of traceability.

Asia-Pacific Reference Frame (APREF) - The purpose of the APREF project is to create and maintain an accurate geodetic framework to meet the growing needs of industries, science programs and the general public using positioning applications in the Asia-Pacific region. The broad objective of APREF is to create and maintain a densely realised and accurate geodetic framework, based on continuous observation and analysis of GNSS data. APREF is a voluntary, collegial, non-commercial endeavour, and there is no central funding source; participating organisations contribute their own resources.

Pacific Sea Level Monitoring Project (PSLMP) - The PSLMP is an Australian Government initiative, funded by Australian Government aid, which enables South Pacific Island Countries to better manage their own environments and contribute to achieving sustainable development. GA maintains a network of GNSS earth monitoring stations for the project to allow absolute determination of the vertical height of the tide gauges that measure sea level.

Budget Information

Australian Government budget information for GNSS work implemented by GA has been summarised under the three categories requested by Kim Geomatics – signal acquisition, processing and dissemination. A different cost structure is used by GA meaning budget figures are approximate-only for the break down below. Noting that GNSS work forms only part of the geodesy program at GA, additional costings for SLR and VLBI facilities are also included. Budget information has been provided in-confidence to support this study.

a) Signal Acquisition (GNSS Network)

Signal acquisition represents the total cost of establishing and operating each CORS in the national network. Establishing a CORS requires capital investment to procure equipment (receiver, antenna, power supply etc), labour and materials. Table 1 estimates the total fixed cost of establishing each CORS at $150,000. This equates to a total cost of $19.5 million for the 130 station network.

Operational costs for power, communications, property leases and travel (amongst other maintenance costs) are ongoing to ensure the site remains functional to acquire the signal. Approximately 100 CORS in the national GNSS network are funded under the AuScope program. State and territory governments cover ongoing operational costs for these sites under the AuScope agreement. A per site operational cost is estimated at $5,000 for this study. This equates to $500,000 in operational expenditure per annum for the AuScope component, and $150,000 for the remaining 30 sites operated by GA.

Total costs incurred by GA can be summarised as $19.5 million for the capital build and a per annum operational cost of $150,000. GNSS and ancillary equipment (e.g. power) are typically depreciated over a 7-year cycle with a replacement cost of approximately $12,000 per year.

Item	Cost
Construction	$50,000
Reference mark including plate, collar, etc.	$2,000
Equipment Huts	$7,000
Solar Panels	$3,000
VSAT Communications	$6,000
GNSS Receiver	$15,000
GNSS Antenna	$5,000
Cables	$1,500
Automatic Weather Station	$15,000
Power Distribution Supply	$5,000
Batteries	$7,500
Freight	$15,000
Travel and Reimbursable	$10,000
Heritage clearance, parcel lease, etc.	$10,000
Cost per station	**$152,000**

Table 1. Estimated cost ($AUD) of establishing a new GNSS CORS site.

b) *Processing (GNSS Network)*

Processing represents the costs of accessing, storing and processing data from the national GNSS network. Processing is needed to produce the data products and services identified previously – AUSPOS, Regulation 13 Certificates, APREF and PSLMP, amongst others. Processing costs include wages, staff overheads, software, software licences, data storage and other network hardware and communications infrastructure. Approximately 10 Full Time Equivalent (FTE) staff process GNSS data at GA. Applying a multiplier of 3 to an average FTE salary of $100,000 equates to a total cost of approximately $3 million for GNSS processing at GA.

c) *Dissemination (GNSS)*

GNSS data products and services are made available online meaning administrative overheads are incurred by the agency. These costs include managing File Transfer Protocol (FTP) networks, cloud data storage and Internet Service Provider (ISP) fees. Dissemination costs are estimated at $1 million per annum for the national GNSS network at GA.

d) *SLR and VLBI*

GNSS is one component of GA's broader geodesy program. Substantial investment has also been made to build and operate SLR and VLBI facilitates. GA operates 2 SLR facilitates, one at Yarragadee in Western Australia and another at Mt Stromlo in the Australian Capital Territory. The Mt Stromlo site cost approximately $10 million to establish, and the Yarragadee site is funded by the National Aeronautics and Space Administration (NASA). Operational costs are approximately $1 million per site, per annum. GA also operates 3 VLBI facilities that were built at a total cost of approximately $4 million. Operational costs vary depending on the number of observation sessions each year, ranging from approximately $200,000 to $500,000 per annum (currently at the higher end of this range).

Long-Term Planning

Long-term planning for the national geodesy program at GA includes:

- Upgrading the national GNSS network to support full multi-GNSS tracking (i.e. GPS, GLONASS, QZSS, Beidou, Galileo, IRNSS);
- Developing a sovereign multi-GNSS analysis capability to improve the accuracy, speed and reliability of positioning in Australia;
- Leveraging multi-GNSS positioning and analysis capabilities to support a growing need for legal traceability and expert certification of GNSS performance, services and equipment;
- Implementing a next-generation time-varying datum aligned to the ITRF to support the higher accuracy positioning expectations of a multi-GNSS future;
- Strengthening collaboration with regional GNSS providers including China (Beidou) and Japan (QZSS) to facilitate site hosting and data sharing arrangements;
- Coordinating and densifying GNSS ground tracking infrastructure to support multi-GNSS analysis and to operationalise the Precise Point Positioning Real-Time Kinematic (PPP-RTK) technique;
- Continuing development and implementation of standards and guidelines for positioning in Australia through the ICSM and its Permanent Committee on Geodesy (PCG) led by GA.

Australia's Satellite Utilisation Policy & the NPI Plan

The Australian Government National Positioning Infrastructure (NPI) Plan remains a key driver of the national geodesy program outlined above. The NPI Plan was developed by GA as part of *Australia's Satellite Utilisation Policy* released in 2013 and provided recommendations on Australia's PNT requirements over the coming decade. The NPI Plan was developed in consultation with state/territory governments and key stakeholders from industry and research with a vision to ensure '*instantaneous, reliable and fit-for-purpose access to position and timing information anytime and anywhere across the Australian landscape and its maritime jurisdictions*.' The Plan remains an internal-to-Government document and did not establish new funding.

The NPI Advisory Board

The NPI Plan recommended the development of a National Positioning Infrastructure Advisory Board (NPI-AB) to provide strategic guidance and advice on designing and implementing the NPI. The NPI-AB was recently established by GA. Ten individual experts were invited from government and industry, and these members represent a wide range of sectors including road transport, engineering, agriculture, spatial, aviation, maritime, PNT and geodesy. The NPI-AB will commission permanent and temporary Technical Working Groups (TWG) to investigate and report on gaps in NPI planning or issues requiring sector-specific expertise.

Strategic Plan for the NPI

GA is drafting an internal Strategic Plan in consultation with the NPI-AB to guide development and implementation of the NPI. The Strategic Plan will address four key areas of NPI development: the need for whole-of-nation governance and leadership; enhancement of GNSS ground tracking infrastructure; development and analysis of high integrity data products and services supporting high precision positioning; and options for delivering these services nationally via ground and satellite communications. It is hoped the document will be released publicly in 2015/2016.

Australian Government PNT Working Group

The PNT Working Group (PNT-WG) brings together key Australian Government agencies involved in PNT, including representatives from the Department of Infrastructure and Regional Development, the Department of Defence, the Department of Communications, the Department of Industry and Science, and the Department of Environment. The PNT-WG provides a point of coordination to discuss PNT priorities and consider whole-of-government issues relating to PNT, such as spectrum management and international collaboration. The PNT-WG was established by Australia's Satellite Utilisation Policy and reports to the Space Coordination Committee (SCC); an interdepartmental committee established to facilitate information sharing on Australian civilian space activities.

GA chairs the PNT-WG and facilitates information sharing between the PNT-WG and NPI-AB (note that the NPI-AB comprises broader membership from across government, industry and research).

The Role of Government

In light of the NPI planning and broader PNT engagement described above, the future role of the Australian Government in the precise positioning domain is viewed by GA as follows:

- Build and operate the primary ground network needed to track multi-GNSS signals;
- Develop multi-GNSS products and services (e.g. precise satellite orbits and clocks) that are optimised for Australia;
- Establish the NPI as a base-level positioning capability that is fit-for-purpose for positioning applications deemed critical in the national interest (e.g. transport);
- Develop the capability to deliver data from the NPI via ground and satellite communications (e.g. by leveraging SBAS and other multi-GNSS capabilities);
- Enforce ground infrastructure and data standards based on international best practice;
- Provide legal traceability of position;
- Develop and operate the capability to monitor and report on the performance and integrity of multiple satellite positioning systems;
- Strengthen partnerships with the international positioning community to link and align public infrastructure and services with international campaigns;
- Encourage industry champions.

GA sees a clear need to strengthen engagement across the Australian Government through the PNT-WG to ensure existing and future GNSS and other PNT resources are optimised for, and made available to the widest audience possible. Australian Government leadership will help to overcome inconsistencies and inefficiencies in the way GNSS infrastructure investment and operations have been managed to date. This includes greater coordination of the mixture of networks currently operated independently by governments and industry across Australia. Strengthening the capabilities of existing GNSS infrastructure, and access to this infrastructure will inform infrastructure and policy development across other key sectors including transport, agriculture and meteorology. This avoids individual sectors attempting to 'go-it-alone'.

Data from the NPI will also strengthen Australia's support for international efforts aimed at monitoring and improving GNSS capabilities and Earth science for the global user community. These global initiatives include the International GNSS Service (IGS), and the United Nations (UN) resolution being put forward to encourage member states to adopt a Global Geodetic Reference Frame (GGRF). Australia co-chairs the GGRF working group with Norway, and the GGRF resolution will be tabled at the upcoming UN General Assembly in 2015.

Industry Collaboration

Australian industry plays a crucial role delivering positioning services and equipment to users. Industry providers are typically the primary interface with users and compete to deliver value-added positioning products and services. Strengthening collaboration between governments and industry is a key objective of the NPI to ensure positioning data is accessible and standardised to support downstream applications.

The future role of the industry in the precise positioning domain is viewed by GA as follows:

- Provide the interface between the NPI and the user community;
- Develop value-added multi-GNSS products and services that contribute to, and take data from the NPI;
- Tailor products and services from the NPI to meet the needs of specific user groups (e.g. engineering, transport, surveying);
- Encourage investment and uptake of multi-GNSS technologies;
- Facilitate skills development in the business and research sectors;
- Assist neighbouring countries with GNSS infrastructure development, technical advice, education and skills development.

Appendix C: Role of Federal Agencies in Canada

C.1. Introduction

The next sub-section of this appendix provides further detail on the Federal GNSS Coordination Board - its governance structure, working groups and activities. Following that each department's mandate or interests are profiled, often in some detail. With that detail and the material in Section 4 on the application of the technology, the potential involvement in augmented GNSS for each department or agency becomes quite obvious.

C.2. Federal GNSS Coordination Board

The Federal GNSS Coordination Board (FGCB) governance structure is given in Figure C-1.

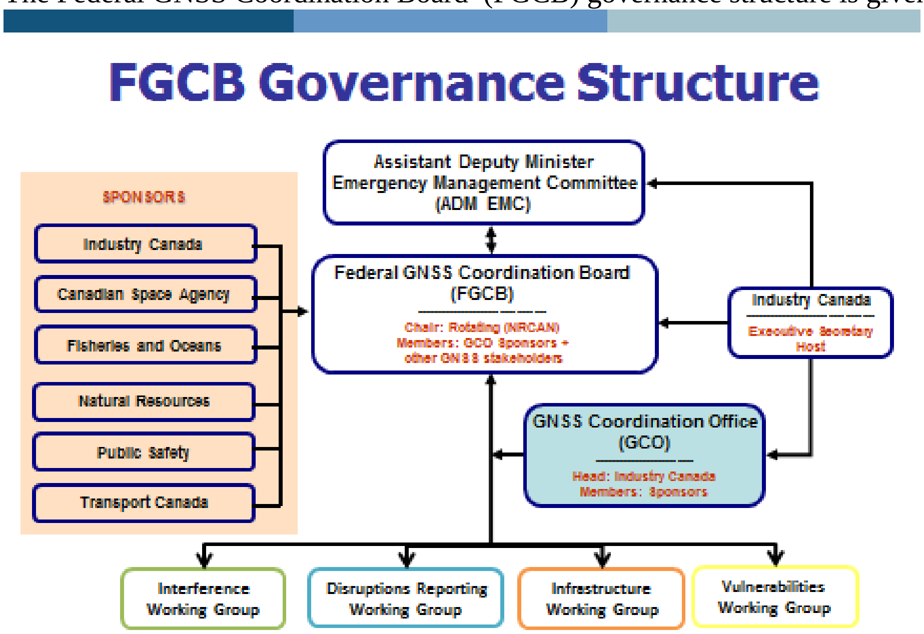

Figure C-1: Federal GNSS Coordination Board Governance Structure (Source: J. MacEachern, Personal Communication, 03/05/15)

Industry Canada hosts the Canadian GNSS Coordination Office (GCO) which provides support for the day-to-day operations of the FGCB and represents the FGCB on GNSS matters within the government and the private sector, and with representatives of foreign governments and international organizations. The GCO supports the FGCB in carrying out its assigned responsibilities and functions and meeting its objectives. There are four working groups under the FGCB with the mandates, participants and tasks outlined in Table C-1 on the page following. The GCO supports the FGCB in carrying out its assigned responsibilities and functions and meeting its objectives by:

- Acting as the federal point of contact for GNSS;
- Providing support for the FGCB operations;
- Developing an annual work plan consistent with objectives and priorities;
- Providing a catalyst/facilitator role for FGCB working groups; and
- Ensuring reports and recommendations are prepared and presented.

Table 9: Federal GNSS Coordination Board Working Group Mandates, Participants and Tasks			
Working Group Name	**Mandate**	**Participants**	**Tasks**
Vulnerability Working Group	To develop an assessment of the risks and potential effects of GPS disruptions on Canadian Critical Infrastructure and recommend measures to prevent and mitigate risks and vulnerabilities.	• Public Safety • Industry Canada • Transport Canada • Fisheries and Oceans • NAV Canada • Defence Research and Development Canada	**Task 1:** Develop a GNSS risk and vulnerability assessment for Canadian CI, taking interdependencies into account. Timeline: Report on results for priority issues to FGCB at end of Year 1 (September 2015) Report on results for remaining issues to FGCB at end of Year 2 **Task 2:** Recommend measures to prevent and mitigate GNSS risks and vulnerabilities: Timeline: Present recommendations to FGCB no later than end of Year 3
Infrastructure Working Group	To develop a coordinated approach to GNSS infrastructure investment across the Government of Canada that considers life-cycle of instrumentation, the advent of new GNSS systems and technologies such as Galileo and GLONASS and evolving user requirements, specifically in Arctic Canada.	• Natural Resources Canada • NAV Canada • Fisheries and Oceans (Canadian Coast Guard)	**Task 1**: Document and maintain a national GNSS infrastructure inventory Timeline: Report on progress to FGCB by end of Year 1 (2015) **Task 2:** Organize yearly GNSS infrastructure workshop Timeline: Report yearly on workshop to FGCB **Task 3:** Assess the need and scope for a user requirement analysis for federal GNSS based services Timeline: Report on progress by end of Year 1 (2015) Present recommendations to FGCB by end of Year 2 (2016)
Interference Working Group	To develop a Canadian approach for GNSS interference monitoring, detection, reporting and mitigation.	• Natural Resources Canada • Transport Canada • Industry Canada • Defence Research and Development Canada • NAV CANADA • Others	**Task 1:** Interference Technical Environment Develop an understanding of space weather impact on GNSS Develop a better understanding of GNSS interference risks. Monitor commercial developments related to both GNSS interference detection and mitigation… **Task 2:** Interference Regulatory Environment Clarify and strengthen penalties related to GNSS interference. Clarify the conditions for GNSS signal repeaters. **Task 3:** Interference Educational Environment Make efforts to educate the public as to issues of GNSS interference and provide information to law enforcement and Canada Border Services as to the nature of and legal status of jammers.
Disruptions Working Group	To develop GNSS disruption alerts and communicate GNSS problems within the Canadian government departments and GNSS users.	• Public Safety (Government Operations Centre) • Industry Canada • Transport Canada • Fisheries and Oceans • NAV Canada	**Task 1:** Collect and assess information with respect to GNSS disruptions **Task 2:** Collect and archive reported disruptions data in a GNSS disruptions database **Task 3:** Provide GNSS disruption alerts

It is clear that the FGCB has a focus on the integrity of the GNSS service to Canada and Canadians. In that sense it has a clear mandate and focus that recognizes the importance **and** use of the GNSS technology. For without important uses, the technology would not be perceived to be important. It is equally clear from the information available that while it acknowledges the importance of the technology's use and while it does engage the transportation sector (notably aviation and marine), it does not directly engage the full range of users, researchers, and industry that have come to rely on GNSS in general and augmented GNSS in particular. Inasmuch as it has a role in the "*coordination of approaches to Canadian GNSS infrastructure investment, evolution and renewal*" as well as "*assessment of opportunities offered by future GNSS systems"* (Industry Canada, Accessed 03/05/15), it would appear important to engage other government departments and agencies whose clients have the potential to benefit from GNSS in general and augmented GNSS in particular.

C.3. Federal Government Departments and Agencies

The agencies involved in the FGCB are the federal departments and agencies that are considered stakeholders in GNSS and associated systems including augmentation. As noted in Table C-1 above and Section 4.9 they are primarily interested in issues related to spectrum management, "spoofing" of signals, and maintaining the integrity of the GNSS system. When one discusses the quality and reliability of data, it is important to note that governments tend to be more trusted than private sector groups when it comes to at least some forms of geospatial information. (Ryerson et al, 2009) It is for this reason that industry routinely cites that their data have been validated by government.

However, there are other reasons for engagement in augmented GNSS than maintaining the quality of data. The following provides a more general commentary on the possible areas of interest of other government agencies and departments or other parts of the government agencies and departments already engaged in the FGCB. The study is by no means exhaustive. In reviewing just the names of federal departments and agencies many more agencies with the potential to use or benefit from augmented GNSS were identified than could be profiled here. Groups who may now or in the future use augmented GNSS include the National Energy Board, Northern Pipeline Agency, the Canadian Environmental Assessment Agency, Parks Canada, and the Transportation Safety Board, among others not profiled here

Except for Industry Canada as the host of the GCO and Natural Resources Canadian Geodetic Survey who are the technical leaders, the remaining government departments and agencies are listed in alphabetical order. For each agency or department identified the current engagement insofar as a quick scan can provide is listed, as well as what the future engagement may be. Given the scope of the contract, what follows is of necessity a simplistic analysis that may well miss engagement that does exist, or suggest future engagement based on technologies that may not develop as expected.

Industry Canada
As noted above, Industry Canada hosts the Canadian GNSS Coordination Office (GCO). Within the spectrum management area it explores interference implications among stakeholders and recommends approaches to deal with the various interference sources. The Minister is also responsible for the Canadian Space Agency.

In the broader context *"industry Canada works with Canadians in all areas of the economy and in all parts of the country to improve conditions for investment, enhance Canada's innovation performance, increase Canada's share of global trade and build a fair, efficient and competitive marketplace. This includes managing Canada's airwaves and overseeing its bankruptcy, incorporation, intellectual property and measurement systems; providing financing and industry research tools to help businesses develop,* *import and export; encouraging scientific research; and protecting and promoting the interests of Canadian consumers."* (Industry Canada2, Accessed 03/05/15)

Taking this broader context into consideration along with the industrial and research capacity in augmented GNSS there would appear to be further synergies that could be built upon. As has been demonstrated in this report, augmented GNSS is an important enabling technology across a number of sectors of the economy of critical importance to Canada. Building on the synergies available in augmented GNSS one can imagine that they would lead to two positive outcomes of importance to industry Canada. The first would be increased efficiencies in sectors of the economy important to Canada. The second would be further development of technology industry and increasing exports of augmented GNSS services and technology.

Canadian Space Agency (CSA)
The CSA falls under the Minister of Industry. As the federal lead on space related activities, the CSA has chaired and actively participates in the FGCB to support the Government of Canada's effort on global navigation satellite systems activities. (Canadian Space Agency, Accessed 3/4/15) The CSA is also interested in the issue of so-called "space-junk," or Space Situational Awareness. There is no reason why augmented GNSS cannot be focused on objects in space.

Natural Resources Canada (NRCan)
The Canadian Geodetic Survey (CGS) fits well within the activities of the Department. "*Natural Resources Canada (NRCan) seeks to enhance the responsible development and use of Canada's natural resources and the competitiveness of Canada's natural resources products. We are an established leader in science and technology in the fields of energy, forests, and minerals and metals and use our expertise in earth sciences to build and maintain an up-to-date knowledge base of our landmass. NRCan develops policies and programs that enhance the contribution of the natural resources sector to the economy and improve the quality of life for all Canadians*. We conduct innovative science in facilities across Canada to generate ideas and transfer technologies. *We also represent Canada at the international level to meet the country's global commitments related to the sustainable development of natural resources. Our Vision: Improving the quality of life of Canadians by creating a sustainable resource advantage."* (Natural Resources Canada, Accessed 03/05/15) In terms of the international level, the CGS is active in a number of international committees. One of its responsibilities should be monitoring and exploring opportunities for Canada to contribute in international GNSS augmentation and related activities to ensure that Canada continues to have a seat on its own merits, not just as a neighbor of the USA.

In addition to the activities of the Geodetic Survey and its parent organization, the Surveyor General Branch, the Geological Survey of Canada has been an important leader in the application of augmented GNSS to the study of earthquakes. Our literature survey suggests that this may be the single most important future safety-related issue associated with augmented GNSS. There are also significant current applications in areas such machine guidance in mining and forest road construction and in understanding issues such as isostatic or post-glacial rebound. In the future one could envision wider application in selective forest harvesting, urban forestry, mineral exploration, and staking of claims. If a "user" group was to be developed, one could imagine that other parts of NRCan should be engaged.

Aboriginal Affairs and Northern Development Canada (AANDC)
"The AANDC supports Aboriginal people (First Nations, Inuit and Métis) and Northerners in their efforts to:

- *Improve social well-being and economic prosperity;*
- *Develop healthier, more sustainable communities; and*
- *Participate more fully in Canada's political, social and economic development - to the benefit of all Canadians.*

AANDC is one of the federal government departments responsible for meeting the Government of Canada's obligations and commitments to First Nations, Inuit and Métis, and for fulfilling the federal government's constitutional responsibilities in the North. AANDC's responsibilities are largely determined by numerous statutes, negotiated agreements and relevant legal decisions. Most of the Department's programs, representing a majority of its spending - are delivered through partnerships with Aboriginal communities and federal-provincial or federal-territorial agreements. AANDC also works with urban Aboriginal people, Métis and Non-Status Indians (many of whom live in rural areas)."(Aboriginal Affairs and Northern Development Canada, Accessed 03/05/15)

The use of augmented GNSS in land survey, local planning and construction, transportation in the north, and mineral exploration together suggest that Aboriginal Affairs and Northern Development Canada will at least be affected by GNSS, if not a major user of the technology. As augmented GNSS is more widely used in the North there would appear to be a need for further outreach in first nation communities on the implications and uses of the technology.

Agriculture and Agri-Foods Canada

The commercial sector unanimously sees precision agriculture to be the largest and fastest growing market for augmented GNSS. Market studies reviewed for this study support that contention. This market has become so important that some service providers have specifically scoped their augmented GNSS systems and the reliability they deliver to serve this market. The range of applications in agriculture, detailed previously in Section 4.3.5, is staggering. In addition to these commercial uses, agricultural researchers routinely use augmented GNSS to return to the same precise location for plot trials and observations. If a "user" group was to be developed, one would expect that Agriculture and Agri-Foods Canada would be involved.

Environment Canada (EC)

"*Environment Canada's mandate is to:*

- *Preserve and enhance the quality of the natural environment, including water, air, soil, flora and fauna;*
- *Conserve Canada's renewable resources;*
- *Conserve and protect Canada's water resources;*
- *Forecast daily weather conditions and warnings, and provide detailed meteorological information to all of Canada;*
- *Enforce rules relating to boundary waters; and*
- *Coordinate environmental policies and programs for the federal government."* (Environment Canada, Accessed 03/05/15)

While the scope of this work prevents an exhaustive study of the literature and publications emanating from EC, it is believed that augmented GNSS is widely used within Environment Canada to return to the same sample plots, to make precise measurements of changes in the environment, movement of materials in mining, tailings, etc. In the future one can imagine that augmented GNSS will play a greater role in identifying, responding to and mitigating environmental problems. The same can be said for activities related to environmental assessments by the Canadian Environmental Assessment Agency. The greatest problem in engaging Environment Canada in a user group would likely be the wide diversity of uses.

Fisheries and Oceans Canada (DFO)

DFO is already deeply implicated in augmented GNSS in that the Canadian Coast Guard operates the e-DGPS used for marine navigation. With the opening of Arctic waters and growing interest in the North there will be expansion of the e-DGPS into the Arctic. As the potential for shipping of diluted bitumen and Liquid Natural Gas from the west coast moves from a plan to reality one can expect too that the DGPS will become even more important. As noted previously, there is significant long-term potential for GNSS to be used in machine-assisted docking.

Foreign Affairs, Trade and Development Canada

"*The mandate of Foreign Affairs, Trade and Development Canada is to manage Canada's diplomatic and consular relations, to encourage the country's international trade and to lead Canada's international development and humanitarian assistance. This includes:*

- *ensuring that Canada's foreign policy reflects true Canadian values and advances Canada's national interests;*
- *strengthening rules-based trading arrangements and expanding free and fair market access at bilateral, regional and global levels;*
- *working with a range of partners inside and outside government to achieve increased economic opportunity and enhanced security for Canada and for Canadians at home and abroad;*
- *managing Canada's support and resources effectively and accountably to achieve meaningful, sustainable international development and humanitarian results;*
- *engaging in policy development in Canada and internationally, enabling Canada's effort to realize its international development and humanitarian objectives."* Foreign Affairs, Trade and Development Canada, Accessed 3/5/15)

Foreign Affairs and Trade Development Canada plays several important roles internationally in space. It is responsible for the Remote Sensing Space Systems Act (RSSSA) and has typically represented Canada in several of the UN fora. It appears to play no role in the FCGB or other aspects of GNSS or augmented GNSS with the exception of being responsible for aspects of export controls that do involve some of the technology. It could be expected that the Department would contribute in three ways in the future:

- Identification of export opportunities for augmented GNSS expertise, services, and technology – an area where Canada has growing expertise and success coming out of university programs across the country. (The Trade Commissioner Service has been supporting several related industries for more than thirty years);
- Identification of and support for development programs in the international financial institutions, particularly related to poverty reduction, sustainable development and social benefits associated with land tenure assurance. This would be a direct response to the recently adopted motion on Geodesy by the UN General Assembly. (United Nations, 2015) Such opportunities also mesh well with Canada's industry capabilities; and
- Identification of investors in the technology coming out of Canada's research.

Health Canada

"*Health Canada is responsible for helping Canadians maintain and improve their health. It ensures that high-quality health services are accessible, and works to reduce health risks.*" (Health Canada, Accessed 03/05/15) Heath Canada is a potential player only if certain technologies become more widely available or used. These include things such as with-in building tracking (in hospitals, for example), tracking patients with ankle-tracking devices, and the like. We mention Health Canada primarily to illustrate what technological changes could bring about.

National Defence

While the military is specifically omitted from this study, the military often responds to civilian emergencies in which augmented GNSS would be potentially very valuable – the Red River flood being but one example where very precise measurements are required. Earthquake response is yet another example of where the military may serve in a disaster. The potential to predict earthquakes is, of course another. With sufficient advanced warning perhaps earthquake mitigation efforts can be anticipated –

closing down gas lines, evacuating bridges, closing the electricity delivery system, stopping medical procedures, etc. From a military standpoint GNSS integrity and spoofing may also be issues. Space Situational Awareness may also be of interest to the military.

Public Safety Canada
"*Public Safety Canada ensures coordination across all federal departments and agencies responsible for national security and the safety of Canadians. Public Safety Canada works with five agencies and three review bodies, united in a single portfolio and all reporting to the same minister. We also work with other levels of government, first responders, community groups, the private sector and other nations."* (Public Safety Canada, Accessed 03/05/15) Public Safety Canada includes the better known RCMP, as well as a number of other agencies that either already use augmented GNSS, or who may well use it in the future. As with the military, issues such as GNSS integrity and spoofing are of interest, as are hazard predictions and emergency response.

RCMP
"The RCMP's mandate, as outlined in section 18 of the Royal Canadian Mounted Police Act, is multi-faceted. It includes preventing and investigating crime; maintaining peace and order; enforcing laws; contributing to national security; ensuring the safety of state officials, visiting dignitaries and foreign missions; and providing vital operational support services to other police and law enforcement agencies within Canada and abroad. The Royal Canadian Mounted Police is the Canadian national police service and an agency of the Ministry of Public Safety Canada. The RCMP is unique in the world since it is a national, federal, provincial and municipal policing body. We provide a total federal policing service to all Canadians and policing services under contract to the three territories, eight provinces (except Ontario and Quebec), more than 150 municipalities, more than 600 Aboriginal communities and three international airports." (RCMP, Accessed 03/05/15) The RCMP uses augmented GNSS for locating people who are lost (through cell phone triangulation), in forensic studies (post-incident studies, for example), and for precise timing related to fraud and other criminal acts. As navigation becomes more precise and autonomous vehicles come closer to reality, it can be expected that the RCMP will be expected to lead policy discussions on matters of safety and policing.

Transport Canada.
The Minister of Transport Canada is responsible for NAV Canada for which the enabling legislation, the Civil Air Navigation Services Commercialization Act (the ANS Act) was passed in 1996. While that may well be the most visible activity associated with the Ministry, its mandate hints at far more potential in the future. That mandate calls for it "*to serve the public interest through the promotion of a safe and secure, efficient and environmentally responsible transportation system in Canada."* (Transport Canada, Accessed 03/05/15)

With more accurate and timely navigation systems based on augmented GNSS it can be expected that new issues in marine, road, rail, and aviation will emerge that will require action and involvement on the part of Transport Canada. Some of these have been mentioned in Section 4.2. Some of these issues are already being discussed in the legal world in terms of liability: a watching brief is clearly indicated.

Appendix D: Regional Information

D.1. Introduction

In Europe the European Union provides a single voice for the region, and it activities are profiled in Section 5.3.2. A number of countries which are not key providers or users of Augmented GNSS have been profiled for each of Europe and Asia in this appendix. The next Sub-section describes the activities of one of the larger players (Germany), one of the smaller countries representative of a technologically sophisticated but still resource oriented country – somewhat like Canada (Finland), and one of the countries from Eastern Europe what has joined the EU in recent years (Hungary). Following that are details on the Asian countries which do not have, or plan to have, their own GNSS space systems. have been profiled

D.2. European Country Profiles

Germany

As would be expected from one of the major countries in Europe, Germany makes substantive government investments in all aspects of GNSS and PPP science and technologies. This includes government research and operations with blurred boundaries that cross into substantial private sector industrial developments. Leica, now owned by Sweden's Hexagon, had its early beginnings in Germany.

The Bundesamt für Kartographie und Geodäsie (BKG) is the German federal authority for Cartography and Geodesy, which is assigned to the Federal Ministry of the Interior. BKG also serves as a Regional IGS Data Center. BKG delivers the geospatial reference systems and the basic geo-information on the territory of the Federal Republic of Germany. BKG's GNSS Data Center (GDC) provides GPS, GLONASS and Galileo tracking data and attendant products. Obtaining data of individual tracking stations is structured according to the affiliation to global, regional and national projects with public and partly restricted access. The availability of original GNSS measurements as observed on tracking stations and supplementary information, e.g., information on satellite's positions (orbits), are key requirements for various user applications. (Bundesamt für Kartographie und Geodäsie, Accessed 2/12/15)

The BKG also delivers a combined satellite-geodetic gravimetric levelling quasi-geoid (SatNivGeoid) that allows the conversion of ellipsoidal GPS heights in ETRS89 with reference to the reference ellipsoid GRS80 and levelling heights in the DHHN92 (NHN) with an accuracy of 1 cm on the plains, 2-3 cm in the highlands and 3-5 cm in the high mountains, for all of Germany. (European Commission, Accessed 2/16/15)

SAPOS is the Satellite Positioning Service of the German national survey. SAPOS works with a nation-wide network of over 260 permanent registering reference stations. It makes full use of GPS, GLONASS, Galileo and local augmentation systems (e.g. EGNOS), and SAPOS delivers a timely and accurate spatial reference in the Europe-wide reference system ETRS89.

SAPOS clients include:

- Cadastral, construction, engineering;
- Line documentation;
- Aerial mapping, laser scanning;
- Hydrography;
- Topographic information acquisition (GIS);
- Scientific and geodynamic studies;
- Agriculture, forestry and land consolidation;
- Car navigation and fleet management; and
- Basic Surveying.

SAPOS offers services with different levels of precision and clock rates of data transmission. The data can be used both for real-time applications as well as data preparation in post-processing. SAPOS can provide users differential GNSS measurements using only a single GNSS receiver. Services include:

Name	Method	Transmission medium	Accuracy	Data format
HEPS	Real Time	Internet, GSM	1-2 cm	RTCM 3.1, 2.3
EPS	Real Time	Internet	0.5 to 3 m	RTCM 2.3
GPPS	Post Proc.	E-mail, download,	≤ 1 cm	RINEX 2.1

Although not a commercial service, SAPOS does charge for these services. (LGLN, Accessed 2/18/15)

The German Research Centre for Geosciences is a Helmholtz Centre. GFZ covers all geo-science disciplines, from geodesy to geo-engineering, and its core areas of expertise include developing and applying satellite technologies and space-based measurement procedures, and in operating geodetic-geophysical measurement networks. Major research topics include:

- GNSS Atmosphere Sounding;
- GNSS Geodynamics;
- GNSS Reflectometry;
- GNSS Analysis Centers and Services; and
- Geodetic and astronomical VLBI.

The GNSS Analysis Centres and Services research area includes activities within the IGS (International GNSS Service), development and improvement of GNSS data analysis software and contributions to the European Galileo.

GFZ has been developing GNSS analysis software for decades. GFZ is also very active in developing new algorithms in order to improve the quality of the IGS products and to enhance the capability of GNSS data processing. GFZ has been developing the GNSS real-time software package, EPOS-RT, which is used for geohazard monitoring (earthquake, tsunami, volcano, landslide), and also to be able to estimate orbit and clock corrections to provide services to users with single-frequency receivers in PPP mode.

GFZ is operating a global GNSS station network (currently ~30 stations) to support scientific research activities like precise satellite clock & orbit determination, radio occultation measurements and crustal dynamics. Additionally operational services for the European satellite system Galileo and various scientific campaigns are supported. (German Research Centre for Geosciences, Accessed 2/18/15) GFZ has 1177 employees including 458 scientists and 198 Ph.D. students. Its annual budget is € 85.4 million. After analysis of their organization charts and other web information, one can conclude that about 5% of their programs are related to GNSS activities. This would equate to 60 staff and a budget of $7M Canadian.

It is important to note that this annual budget figure is in addition to the substantial investments made by the German Aerospace Agency (DLR) in GNSS research, operations, applications development, and commercialization.

The ongoing German government investment in GNSS science and technologies continues to spawn a growing array of mid to large sized companies. One example is Geo++ GmbH, founded in 1990, which now enjoys a quarter of a century of experience in the field of GNSS-based positioning for static and kinematic applications in geodesy and navigation. Its work includes system conception, development, and analysis both of own products and also as clients or partnerships with other well-known manufacturers and sellers of positioning systems. With their sister company, GeoService Satellitengestützte Vermessungen, they are active in such areas of consulting, surveying and analysis.

Their current flagship product is GNSMART (from Global Navigation Satellite System – State Monitoring And Representation Technique),which contains all the necessary components for linking to reference stations which can then provide complete coverage of reference data to enable position fixing with centimeter accuracy in real-time. (GEO++, Accessed 2/18/15)

Finland

The Finnish Geospatial Research Institute (FGI), formerly the Finnish Geodetic Institute, carries out national geodetic base measurements and ties them to the respective measurement of neighbouring countries and international systems. The FGI also created and maintains Finland's national coordinate and height systems. EUREF-FIN is a national realization of the European ETRS89 coordinate system and is the official coordinate system in Finland. The FGI recently renewed its GNSS reference network in 2014. This is referred to as the Finnish Permanent GNSS (FinnRef) network.

In addition to re-capitalizing the older stations, many new ones were established to make the GNSS network denser. The renewed FinnRef network consists of 19 GNSS reference stations that receive signals from GPS, Galileo and GLONASS. Some of these stations belong to the global IGS network and to the European Permanent Network (EPN).

The FinnRef network is part of a Nordic GNSS network, which was established on the initiative of the Nordic Geodetic Commission and the Directors General of the Nordic Mapping Authorities in 1990's. This Nordic group was an early attempt to share information across several close countries. Working together has been a hallmark of the GNSS community in much of Europe and North America. In effect, the EU has taken the idea of grouping countries together in this field one step further.

The FGI FinnRef has also begun to offer a new open positioning real-time DGNSS (Differential GNSS) service, which is providing positioning corrections based on the error modelling of the code observation at the FinnRef stations. The system required a dense network to provide the more accurate positioning information (as correction accuracy decreases with the distance to the nearest station). The FGI also offers a coordinate transformation service offers coordinate transformations between different national reference systems. (Finnish Geospatial Research Institute, Accessed 2/14/15)

It is noteworthy that these 19 stations, plus all of the supporting ground segment (computers, communications, 24/7 capacity, people) would appear to be a recent substantive public good government reinvestment by a small, first world nation. (See Improving Network Integrity of Finnish Permanent GNSS Network FinnRef) In that sense, it is instructive that one of the most technologically advanced nations in Europe and a major player in the forest industry has seen fit to invest in the technology at the national level at a time when the country is having some budgetary difficulties.

Hungary

The Hungarian Government operates FÖMI, the Hungarian Institute of Geodesy, Cartography and Remote Sensing, as well as a Satellite Geodetic Observatory, and their GNSS Service Centre.

Existing infrastructure includes about 32 GPS/GLONASS reference stations, hundreds of RTK stations 10000 networked reference stations (which we assume means survey monuments), and over 150,000 clients. Services include real-time data, decimeter DGPS corrections, and real-time, accurate RTK cm, and network RTK corrections. (Hungarian Institute of Geodesy, Cartography and Remote Sensing, Accessed 2/12/15)

It is noteworthy that FÖMI is struggling with their relationships with the many rapidly emerging commercial RTK/PPP suppliers. The RTK/PPP markets include: survey, engineering, construction, utilities, machine control, deformation monitoring, precision agriculture, mapping/GIS, and airborne laser scanning. This is estimated at hundreds of thousands of individual clients. The authors of this report suggest that this number does seem very large given the size and population of the country.

The goal of FÖMI is a symbiotic relationship with the commercial network of PPP-RTK service providers. Benefits of coexistence for the FÖMI network RTK service providers include the market boom, more robust services, the use of PPP-RTK as a fallback solution, and independent monitoring of reference station coordinate stability. The benefits of coexistence for commercial PPP-RTK services start with the fact that PPP-RTK is not possible without local or regional augmentation. Also transformation from the global reference to the local grid is required, necessarily a service of government.

That said, the advice of the Head of FÖMI to government Network RTK service providers was to be prepared, and start cooperating early with commercial PPP-RTK service providers, otherwise in his words, "… you may have to do something else in 4-5 years' time". (Horvath, 2012) It is likely that he was advising government geodetic organizations in small to medium size countries to collaborate with local industry, and to have a mutual, clear understanding about what their respective roles are as a matter of survival.

D.3. Asian Country Profiles

Korea

Korea is to the major players in the Asia-Pacific region somewhat like Canada is to the major player in North America: it is smaller in terms of population and power (both economic and military), but has been involved in the technology and its use for longer than other smaller players in their part of the region. Korea has the 15th largest economy in terms of GDP and is seen as a wonderful market for a range of technologies and services. (European GNSS Agency, Accessed 2/18/15; European GNSS Agency, 2013) It is especially interesting in that it has a large automotive industry as well as a major mobile communications industry including GNSS-enabled smartphone manufacturers. Of particular interest is the regulatory environment that ensures that all handheld phones in Korea must support GNSS. Furthermore, location based services are also important in the country.

Korea developed a GNSS Technology Council (GTC) in 1994 with the support of Korea's Ministry of Information and Communication. It was started by individual experts from universities, research institutions, and industry associated with GNSS technology. It was developed to promote the exchange of academic and technical information and to support research and development activities with respect to GNSS technology. GTC has hosted annual national conferences entitled "GPS Workshop" where technical and policy issues on the essence of GNSS technology and its wide applications are presented and discussed. In addition, tutorial sessions on the fundamentals of GNSS including GPS, DGPS, GPS receiver technologies have been offered. In 1999 it started to organize an annual "International Symposium on GPS/GNSS" to promote international co-operation. GTC also agreed to co-host and participate in a number of international symposia to share ideas between GNSS experts and decision makers. In October 2014 Korea's GNSS Society hosted the International Symposium on Global Satellite Navigation Systems. Korea is well covered by 70 CORS stations. Land survey is a major application and precision agriculture is of interest – there is a Korean Society for Precision Agriculture. (See http://www.precisionag.or.kr/ - in Korean). Research is being done in areas such as remote tolling for vehicles and Movea (Accessed 2/20/15) has demonstrated a pedestrian navigation solution.

South East Asia: Malaysia, Indonesia and Thailand

Malaysia

Malaysia has already been mentioned for its interest in precision agriculture. Beginning in 2001 it regularly hosted a series of symposia dealing with geo-information and GNSS. These meetings started small but have hosted as many as 300 people from 15 to 20 countries. More recently Malaysia has hosted Map Asia and other more broadly based meetings. That Malaysia has a significant land survey activity was recognized internationally when a Malaysian, Mr. Chee Hai Teo, was named President of FIG. The 2014 International FIG Conference was held in Kuala Lumpur. Land survey would appear to be the major use of augmented GNSS in Malaysia.

Indonesia

Indonesia provides something of a contrast to the countries discussed to this point. While installing the basic infrastructure to use augmented GNSS began as early as 1995 with three CORS stations in place by 1996, progress was slow until 2007. Even as late as 2009 Bakosurtanal (the mapping agency for the country) had but 30 CORS stations – primarily for early tsunami warning – but was said to need another 100 for other purposes. By 2009 the Land and Building Taxation Agency had installed nine CORS stations on several of the major islands (Sumatra, Java, Bali and Kalimantan), while several oil companies and mining companies have more than 30 such stations on its 922 inhabited islands. But the hallmark at that time was lack of cooperation between the many institutions and agencies with an interest in GNSS. (Sunantyo, 2009) As with the Philippines, Leica installed at least one CORS station in association with the taxation agency and their local agent Almega Geosystems. By 2014 (Adiyiya, 2014) Bakosurtanal (now called the Geospatial Information Agency – or BIG using the first letters of the words in the Bahasa language) operated 124 CORS stations, 19 supported by Germany for tsunami warning. Today the Indonesian operation center InaCORS consists of multiple servers that receive, process manage and store the data and provide services on a 24/7 basis. It is still not clear that there is a great deal of cooperation between those operating the various stations.

Thailand

The UN has been a vocal proponent and supporter of GNSS in developing countries through the UN Office of Outer Space Affairs, based in Vienna. Thailand hosts the major UN office for Asia and operates a sophisticated hub for air traffic in Bangkok. It is not surprising that it was an early adopter of GNSS technology in certain key sectors. However, Thailand does offer yet another view of the varied situation in Asia. Today it uses basic GNSS technology for vehicle tracking and traffic management on expressways and toll roads. Logistics companies use the technology to increase efficiencies. Vehicle tracking was growing at 10-30% per year. (Narupiti, 2011) However, unlike in some other countries, GNSS activities are under the Military in the Royal Thai Survey Department (RTSD). The RTSD is located at the Royal Thai Armed Forces Headquarters in Bangkok. The same office complex contains a number of civilian agencies, including the Geo-Informatics and Space Technology Development Agency which is responsible for the Thai space program, remote sensing and a significant part of the geospatial data infrastructure. As with many military agencies in the mapping field, the RTSD was slow to come to the belief that sharing geo-information was in the best interests of the country. This view is believed to have slowed development of GNSS augmented services until as late as 2007 when the existing open data policy for remote sensing was confirmed by the military and extended to other geospatial data. (Ryerson and Peanvijarnpong, 2007) One can expect to see continued growth in the use of GNSS augmented services in everything from land survey to monitoring water levels related to flood mitigation.

Less Developed Countries

Bangladesh

In Bangladesh lower accuracy GNSS has been used by the remote sensing agency and others for flood mapping, crop assessments, flood recovery, and a variety of similar applications that required less precision. (Sarker, 2011, 2014) Bangladesh is an example of a less well-developed country whose adoption of augmented GNSS was delayed compared to more developed countries. The first six permanent CORS stations and a server began operation in December of 2011. Now RTK services can deliver a more precise location for, primarily, land survey applications. Like Thailand, the Survey of Bangladesh is under the military. (Survey of Bangladesh, Accessed 2/9/15)

Small Island States

Other countries with a need for precise information from GNSS augmentation systems, especially in terms of height, are the island nations of the Indian and Pacific Oceans. The highest point of land in the Maldives (other than the land fill) is 2 meters. Changes in sea level and tsunami warning systems are, obviously, critical.