Precise positioning services in the construction sector

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

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

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Executive Summary

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

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

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

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

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

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

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

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

Key Findings

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

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

1 Introduction

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

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

2 The construction industry in the Australian economy

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

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

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

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

3 Use of precise positioning in the construction sector

3.1 Construction and engineering surveying

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

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

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

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

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

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

Source: SKM

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

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

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

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

through the sophisticated integration of precise positioning through augmented GNSS.

Benefits

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

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

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

3.2 Machine Guidance

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

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Box 2 Case studies of savings from augmented GNSS

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

Source: SKM

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

Benefits

The benefits of augmented positioning in supporting machine guidance are;

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

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

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

3.3 Asset Management

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

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

3.3.1 Benefits

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

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

These benefits include:

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

3.4 Emerging Technologies

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

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

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

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

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

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

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

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

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

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

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

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

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

4 Productivity and economic impacts

4.1 Accumulated productivity impacts

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

Table 1 **Direct impacts**

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

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

Data source: Case studies, interviews and literature review.

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

Table 2 **Direct impact – 2020**

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

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

Data source: Case studies, interviews and literature review.

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

Table 3 **Construction sector productivity impact**

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

Note: Productivity expressed as a percentage of costs

Data source: ACIL Allen, SKM, case studies, literature research.

4.2 Impact on sector output

The productivity impacts summarised in Table 3 were used as inputs to ACIL Allen's Computable General Equilibrium (CGE) model, Tasman Global[3], to estimate the impact that productivity improvements from the use of augmented GNSS has had on the Australian economy in 2012 and the potential benefits that could arise by 2020[4].

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

Table 4 **Impacts on output**

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

Note:

Data source: ACIL Allen modelling

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

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

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

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

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

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

Appendix A Case Studies

A.1 Construction surveying and set out

A.1.1 Sugarloaf Pipeline

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

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

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

Data source: SKM and John Holland

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

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

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

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

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

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

Data source: SKM and John Holland

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

A.1.2 The East Link project

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

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

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

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

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

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

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

A.1.3 Benefits

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

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

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

A.1.4 Productivity Estimates

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

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

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

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

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

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

A.1.5 Adoption Costs

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

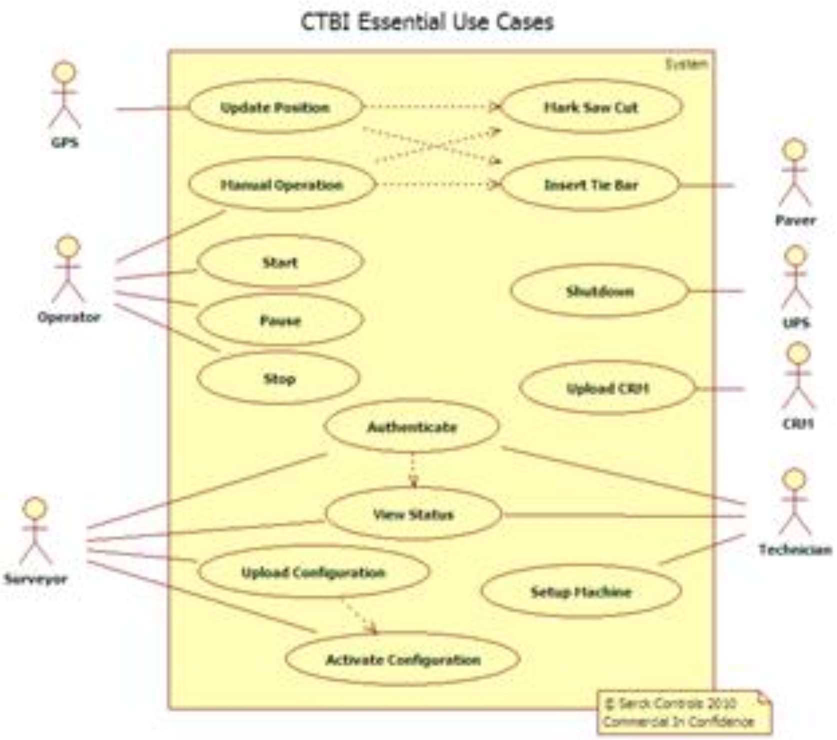
A.1.6 Concrete Tie Bar Insertion Project (innovation project)

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

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

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

Figure 3 **GNSS assisted tie bar sequencing**



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

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

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

A.1.7 Productivity Estimates

The improvements in productivity identified in the case study include:

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

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

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

A.1.8 Adoption Costs

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

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

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

A.2 Machine Guidance

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

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

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

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

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

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

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

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

Data source: Ultimate Positioning (Trimble Distributor)

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

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

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

A.2.1 Benefits

The benefits identified include

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

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

A.2.2 Productivity Estimates

The productivity estimates provided by the case studies were:

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

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

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

[6] note this does not include structural construction

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

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

22,93 % savings in time

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

97,65 % savings in time

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

22,19 % savings in fuel

Data source: University of Reykjavik

Earthworks represent up to approximately 10-15% of non-residential construction activities (Allen Consulting 2008 and SKM estimates). The benefit from machine guidance in earthmoving is approximately 10 per cent to 30 per cent. Based on this is an estimate of non-residential construction industry benefit of approximately 1.5 per cent to 3 per cent has been used for the purposes of economic modelling.

Productivity is achieved through a number of scenarios. Reduction in on-site staff, including surveyors, who would previously be required to supply cut and fill pegs to any earthworks operation is a key component of saving. However it is the reduction in material double handling that produces the most obvious savings to any earthworks. Previously, without guidance controls, the effectiveness and efficiency of operation were reliant on the experience of foreman and operator which still resulted in plentiful double handling. With the advent of guidance systems, relatively inexperienced operators can be more effectively guided through the task to maximise the efficiency of the earthworks. This is also a crucial point to note given the relative skill shortage the construction industry is seeing in experienced machine operators.

Machine guidance systems also facilitate applications that weren't previously possible, such as pile driving from barges as part of the dredging and port construction services. Examples like this suggest that as machine guidance is more readily adopted more and more applications will be discovered.

A.2.3 Adoption Costs

Benefits of machine control clearly outweigh the initial investment and are precisely why the technology has been rapidly adopted throughout several industries (mining, civil engineering, and construction) given the savings of efficiency through the benefits described above.

The typical machine guidance costs range between $60,000 and $80,000 per machine based on current estimates provided and dependant on exactly what machine the system is used to control (i.e. graders are more expensive to fit than dozers). The vast majority of the adoption costs are centred around the GNSS hardware, with 2D systems (based solely on inertial sensors) ranging between 20 and 30k to fit out, but increasingly becoming phased out amongst new markets.

Another key component of the initial investment is the establishment of localised spatial data infrastructure and communication equipment (i.e. radio signals). This tends to be the industry standard at the moment, however with densification of CORS and improvement in communication coverage, localised base stations may well be surpassed in many areas where coverage is sufficient. This could save approximately $20,000 to $30,000 capital investment.

Currently within the construction industry it is estimated that there is up to 2,500 machines across Victoria alone with indicative or full machine guidance systems. Across Australia this estimated is projected to be around the 10,000 mark. With increasing exposure to machine guidance, there is an upward trending rate of adoption, estimated at around 10-15% per annum. For the purposes of modelling we have assumed a modest increase to 30 per cent by 2020 recognising some constraints with availability of suitable augmentation signals in some areas.

A.3 Limiting Factors

With lack of supporting infrastructure, precision GNSS often has to depend on localised GNSS reference networks that can be more expensive to setup, maintain and administer. Accordingly, wide scale GNSS augmentation tends to be limited to large infrastructure projects and is not as readily available to smaller construction projects (given associated costs). Smaller projects within some metropolitan and regional areas can be supported via existing positional infrastructure, particularly in New South Wales, Victoria and South Australia, however most projects could benefit greatly from extension and densification of CORS networks.

There is also a limitation in many applications of machine guidance given the increasing reliance of precision GNSS as a guidance sensor. This can cause frustration and downtime given that GNSS is not always applicable to some site conditions (especially in areas where satellite coverage is greatly obscured – such as within large trenches). This is somewhat alleviated by the introduction of other sensors within guidance systems. In the longer term other technologies such as Locata may address some of these gaps in service. GNSS modernisation will also provide more dependable and available signals and constellation geometry to support operations.

Appendix B Adoption

It is apparent that there is already significant take-up of a number of precise positioning applications throughout the construction industry including both site surveying and machine guidance, which are increasingly becoming convergent. Whilst this is largely constrained to larger scale infrastructure projects, the increasing availability of both precise positioning services and machine guidance systems is lending itself to an ever increasing adoption rate, with large economic benefits being realised by the companies at the forefront.

B.1 Adoption Factors

Adoption is driven by a number of factors. More broadly speaking, the classic textbook reference by Rogers (1964) identified a five-step decision process involved in technology adoption and diffusion:

- Knowledge – potential adopter becomes aware of an innovation but has no particular opinion of it (this could be via advertising or through word-of-mouth)
- Persuasion – the potential adopter seeks further information to help form an attitude toward the innovation
- Decision – the potential adopter engages in activities that lead to a choice to adopt or reject the innovation (the process is internal to the person and can be difficult to measure empirically; however considerations of price and perceived usefulness/necessity will play into this decision)
- Implementation – the innovation is adopted and put into use (e.g., user installs geospatial data software or uses car navigation aids)
- Confirmation – person evaluates the results of an innovation-decision already made which may affect decisions such as whether to continue using the innovation or return to previous status quo (e.g. remove software or return car navigation aid).

Some of the factors that the research suggests are important in the further adoption of precise positioning technologies are discussed below.

B.1.1 Ubiquitous Positioning

Given the majority of adoption of positioning applications is for infrastructure and earthworks related activities, there is a whole realm of further potential within the structural construction sector. Similar to mining, advances in positioning technology may further the likelihood of concepts such as indoor positioning, or at least positioning in areas obstructed from satellite view. Examples of the Locata terrestrial based system facilitating deep pit activities maybe a concept explored for that of structural construction in the future, however as it stands, the adoption of GNSS is generally limited to open sky large scale construction endeavours largely associated with mass infrastructure development.

B.1.2 System Interoperability

The increasing convergence of surveying site duties and machine guidance will further enable adoption of precise positioning within the immediate future. Already great progress has been made by position system companies to ensure the interoperability and exchange of precise site data between survey design and machine guidance.

B.1.3 Industry Standards

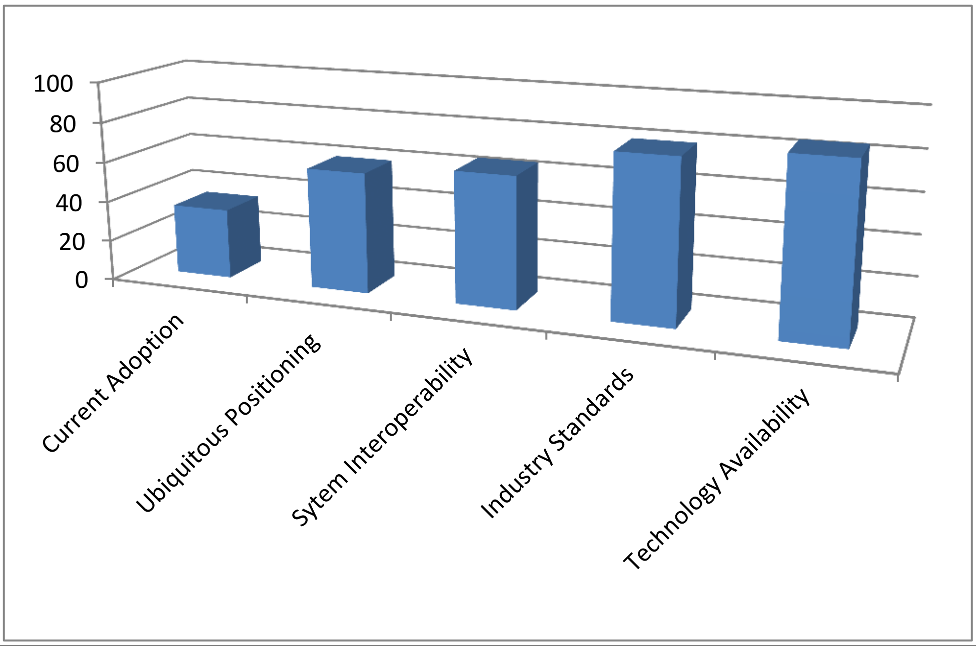
An important adoption factor to be discussed is the development of industry standards that may well require a number of construction stakeholders to conform to machine guidance project implementation as part of the conditions of contract. Such stipulations will drastically increase the adoption rates of the technology and encourage smaller players to make the investment into more advanced systems.

B.1.4 Technology Availability

Larger companies at the forefront of large-scale infrastructure development have already made significant investment into machine guidance to improve the efficiency of their operations. Such large scale investment has yielded technological innovation and integration and as a result companies have started to realise large benefits. Smaller contracting companies are still somewhat behind in the adoption of automation technologies given the up-front costs needed to secure the technology and integrate it into working practices.

Figure 7 demonstrates the estimated rise in adoption level as the various adoption factors are overcome through developments.

Figure 7 **Adoption levels and factors**



Data source: SKM

The adoption factors previously discussed and indicated within figure 11 are seen as the major impediments to adoption. As these are partially or fully overcome there will be a direct correspondence with construction adoption of positioning systems and technologies. The table below is speculative but an attempt to project the likely technological and structural advances in positioning adoption factors.

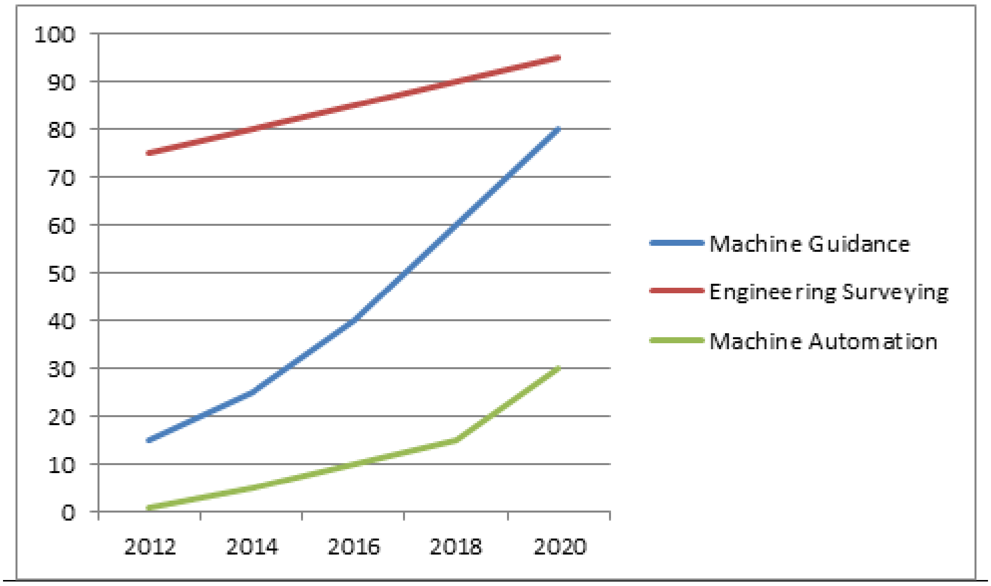
Table 1: **Estimated Timeframe for overcoming adoption factors – Construction**

	Optimistic	Medium	Conservative
Ubiquitous Positioning	2014	2018	2025
System Interoperability	2014	2018	2020
Industry Standards	2014	2018	2025
Technology Availability	2014	2018	2025

Data source: SKM

The graph below displays the likely increase in adoption of GNSS precise positioning technologies amongst the Construction sector. Three curves have been estimated based on the implementation of GNSS positioning amongst construction applications identified throughout the case studies

Figure 8 **Adoption Curves**



Data source: SKM

Appendix C Social and Environmental

Any major construction project is going to have an influence on its immediate environment. This is an inevitable consequence of development. Obviously, the key aspect of existing and future development projects is to minimise the immediate negative implications and maximise the positive influence of the development.

Precise positioning help deliver projects in a more sustainable and equitable fashion by maximising both the efficiency of the operation and minimising the material wastage associated (especially in regard to earthworks operations). This is achieved, via integrated positioning systems that aid machine guidance, GNSS, in particular works to reduce direct impacts such as fuel use, carbon emissions and excessive material waste.

There are many potential social impacts of construction and engineering operations. The prime examples include the impact of large scale infrastructure developments on the immediate community. Such impacts are often vigorously debated by community representatives with particular concerns expressed frequently regarding impacts such as sustainability, people displacement and inconvenience. Effective management and efficiency improvements (via machine guidance and GNSS precise positioning) will help alleviate some of these direct concerns, however construction and project delivery is inevitably fraught with larger scale opposition.

The ability of works to relay information to the community (via spatial information), is of particular importance to any project. An example being the update of progress and impact on the Sugarloaf pipeline, where frequent Maps were published showing the progression of the current works and the boundaries associated with the construction. Such maps were reproduced quickly and efficiently through site surveying activities that utilised GNSS within the data capture phases of the project. This also touches on the area of asset management and replication of as-builds' to document and manage the constructed assets (infrastructure).

Finally, the benefits of operational efficiency, sustainability and management over the entire project lifecycle are a major positive for the construction sector. Such benefits lead to better public perception of the industry and more scope for future approvals on works.

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