SBAS Test-bed Demonstrator Trial

Economic Benefits Report

June 2019

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Contents

Glossary

There are a range of technical terms and concepts that are used throughout this report. These have been separated into 'key terms' and 'acronyms'. Key terms are terms or phrases that are used frequently throughout the report and have been deliberately defined to remove any ambiguity about their meaning. The acronym list is a representation of all abbreviations used throughout the report.

Key terms

Term	Description
Absolute positioning	Absolute positioning refers to the method of positioning using a single GNSS receiver. The position is determined using only the measurements made on that receiver. It is the opposite to the relative positioning for which the receiver position is determined relative to another receiver whose position is known.
Accuracy	Closeness of a measured position to the true position. It is commonly quantified using the mean of measured positions over a specified period of time.
Accuracy levels	Accuracy levels have been defined as follows: • Centimetre-level: 0-10cm • Decimetre-level: 10-30cm • Sub-metre level: 30cm-1m • Metre-level: 1-10 m
Availability	The percentage of time the system is usable for positioning within a given period. This can be affected both by issues with the provision of signals and by the receiver environment.
DFMC	Dual Frequency Multi-Constellation SBAS is a second generation SBAS service. Unlike the single frequency SBAS that only provides corrections to Global Positioning System (GPS) satellites on the L1 frequency, DFMC provides corrections on two frequencies on any number of GNSS constellations. This has many advantages compared to the single frequency SBAS.
Integrity	The measure of trust that can be put in a measured position. This includes the ability of the system to issue timely warnings to users when the system should not be used. Apart from this general definition, the term integrity also has a technical definition exclusive to the aviation sector, where it is described by the Protection levels (see definition below).
L1 SBAS	Single frequency SBAS is an absolute positioning method that provides corrections to L1 GPS signals to improve accuracy, integrity, and availability as compared to a standalone positioning solution.
Operational SBAS	An operational SBAS is a system that has been certified as an aviation Safety-of-Life (SoL) SBAS system by the civil aviation regulator. For the purposes of this report, L1 SBAS and DFMC are treated as SoL certified systems, whilst PPP is uncertified.
Precise Point Positioning (PPP)	PPP is an absolute positioning method that can achieve decimetre-level horizontal accuracy after a convergence period of tens of minutes.
Precision	Refers to the spread of repeatedly measured positions around their mean. It is commonly quantified using the standard deviation.
Protection level	In aviation 'protection levels' describes a bounding region (horizontal and vertical) that contains the true position of the aircraft to a specified level of confidence. When the protection level reaches a certain limit (set by the application), an alert is issued to the user and guidance is terminated by the user equipment. It is possible that similar integrity messages could be developed for use in road, rail or maritime sectors in the future; however, the implementation of these messages will differ based on the requirements of each sector.
Relative positioning	Relative positioning refers to a method of positioning using two or more receivers. The position of the unknown receiver (rover) is determined relative to one or more receivers whose position is known. These receivers are commonly referred to as base (or reference) stations. Relative positioning works on the premise that for two nearby stations the errors affecting GNSS will be similar and hence, if the errors are known at the base station, they can be used to correct the position of the rover.
Robustness	Relates to spoofing and jamming and how the system can cope with these issues. Robustness can be improved by authentication information and services.

Term	Description
Safety of life	Refers to the use of an operational SBAS in safety-critical applications, typically in the transportation sectors. Essentially, a set of prescriptive performance requirements must be met (and certified) before an operational SBAS can be relied upon. For the aviation sector, safety-of-life standards are set by the International Civil Aviation Organisation and national legislation. Their standards require performance that is more stringent than most other applications of an operational SBAS, as a degradation in the navigation system performance without a notice within the specified time to alert would endanger lives.
Test-bed	A Test-bed is a platform for conducting rigorous, transparent, and replicable testing of new technologies. The use of SBAS Test-beds is a well-established method for reducing risk by evaluating technical performance and assessing costs and benefits for an operational SBAS.
Unquantified benefits	There are three types of benefits that have not been quantified in this analysis: 1) Qualitative benefits: These have been presented within each sector Chapter and represent the findings of discussions with Demonstrator Projects; however, insufficient evidence existed to quantify these findings. 2) Additional applications: These have been presented in the additional applications Chapter and have not been confirmed with Demonstrator Projects, nor is there sufficient evidence to quantify these findings in this report. 3) Other applications: These are the 'unknown, unknowns'. These have not been described or quantified in this report.

Acronyms

Acronym	Full Form
ABS	Australian Bureau of Statistics
ADOC	average direct operating cost
AHRT	Auckland Helicopter Rescue Trust
AIS	automated identification systems
AMSA	Australian Maritime Safety Authority
APV	approaches with vertical guidance
ATAP	Australian Transport Assessment and Planning
AV	automated vehicles
Baro-VNAV	Barometric vertical navigation
b	billion
BCC	Brisbane City Council
CASA	Civil Aviation Safety Authority (Australia)
CAA	Civil Aviation Authority (New Zealand)
CAD	computer-aided design
CAS	collision avoidance system
CAT	category
CAV	connected and automated vehicle
CFIG	Corrigin Farm Improvement Group
CFIT	Controlled Flight into Terrain
C-ITS	co-operative intelligent transport system
CORS	Continuously Operating Reference Stations
CQU	CQUniversity Australia
CTF	controlled traffic farming
CV	connected vehicles
DALYs	disability adjusted life years
DBYD	dial before you dig
DDCs	delays, diversions, and cancellations
DELWP	Department of Environment, Land, Water and Planning
DFMC	Dual Frequency Multi-Constellation
DGNSS	Differential Global Navigation Satellite Systems
DGPS	Differential GPS
DP	dynamic positioning
EML	electromagnetic locators
eRUC	electronic RUC
EY	Ernst & Young
FCNSW	Forestry Corporation of NSW
FFH	falls from height
FFVH	forage front virtual harvesting
GBAS	Ground-Based Augmentation Systems
GCP	ground control points
GDP	gross domestic product
GIS	Geographic Information System
GNSS	Global Navigation Satellite Systems
GNSS-RF	Radio-Frequency enabled Global Navigation Satellite Systems

Acronym	Full Form
GPR	ground penetrating radar
GPS	Global Positioning System
GTK	gross tonne kilometres
IALA	International Association of Marine Aids to Navigation and Lighthouse Authorities
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ILS	Instrument Landing Systems
IMO	International Maritime Organization
ITS	intelligent transport systems
LED	light-emitting diode
LiDAR	Light Detection and Ranging
LPV	localiser performance with vertical guidance
m	million
MIAL	Maritime Industry Australia Limited
MoT	Ministry of Transport (New Zealand)
NRTK	Network Real Time Kinematic
NTK	net tonne kilometres
NZTA	New Zealand Transport Agency
OEM	original equipment manufacturers
PANSW	Port Authority of NSW
PDS	proximity detection system
PPP	Precise Point Positioning
PPU	portable pilot unit
PV	present value
QUT	Queensland University of Technology
Rex	Regional Express
RF	radio-frequency
RFDS	Royal Flying Doctor Service
RFDSSE	RFDS south-east
RFID	radio frequency identification
RINEX	receiver independent exchange format
RTK	Real Time Kinematics
RUC	road user charging
SA2	Statistical Area Level 2
SAR	search and rescue

Acronym	Full Form
SARPs	standards and recommended practices
SBAS	Satellite-Based Augmentation System
SLAM	simultaneous localisation and mapping
SoL	safety of life
Stats NZ	Statistics New Zealand
TEU	Twenty-foot equivalent unit
TSRs	temporary speed restrictions
TTK	tare tare kilometres
UAV	Unmanned Aerial Vehicles
UHF	ultra-high frequency
UKC	under keel clearance
UNSW	University of NSW
USDOT	US Department of Transport
V2I	vehicle-to-infrastructure
V2V	vehicle-to-vehicle
VCS	vehicle control system
VF	virtual fencing
VKT	vehicle kilometres travelled
VOC	vehicle operating costs
VRT	variable rate technology
WAAS	(US) Wide Area Augmentation System

The power of precise positioning

Signals from a Satellite-Based Augmentation System (SBAS) have a number of advantages and can improve the accuracy of Global Navigation Satellite Systems (GNSS) from ± 5 to 10 metres to within 10 centimetres. This improvement in positioning performance is expected to drive the development of new technologies and processes, providing significant benefits to the Australian and New Zealand economies through improved productivity, better health and safety outcomes and reduced environmental impacts. The SBAS signals are anticipated to set the foundation for a present value (PV) AUD $7.6b economic impact on the Australian and New Zealand economies over 30 years. This foundation is exclusively based on the benefits identified through the SBAS Test-bed Demonstrator Trial.

What is SBAS?

SBAS is a correction service for standalone GNSS observations that has been implemented in several regions around the world, including the United States, India, Europe, and Japan. SBAS signals fundamentally improve the accuracy, integrity, and availability of standalone GNSS signals (or what is more commonly referred to as GPS in Australia and New Zealand).

What is the SBAS Test-bed Demonstrator Trial?

The SBAS Test-bed Demonstrator Trial aimed to support Australia and New Zealand's decision to pursue the implementation of an operational SBAS, which in practice would transmit the SBAS signals. Testing of the SBAS signals, which includes three types of signals called SBAS L1, SBAS Dual Frequency Multi-Constellation (DFMC) and Precise Point Positioning (PPP), took place from October 2017 to January 2019, with FrontierSI evaluating their effectiveness and application across 10 sectors through 27 Demonstrator Projects.

Who has been involved?

The SBAS Test-bed Demonstrator Trial has been a collaborative effort from Demonstrator Projects and sector participants representing the following sectors: agriculture, aviation, construction, consumer, maritime, rail, resources, road, spatial, and utilities. These parties have aimed to make the content in this Economic Benefits Report relevant for their respective sectors. FrontierSI has provided considerable technical and logistical support, to ensure the benefits of the SBAS signals are interpreted and applied correctly, whilst EY has provided economics support to guide ways in which benefits can be quantified.

Benefit highlights

The following represent a selection of significant benefits anticipated from the deployment of an operational SBAS across Australia and New Zealand. These benefits have all been constrained to the findings of the respective Demonstrator Projects and do not represent a full assessment of all economic benefits that could accrue. However, all benefits noted below are directly attributable to the SBAS signals and take into account concepts such as uptake, adoption and attribution. All figures are in Australian dollars unless otherwise stated.

PV$820m in feed and fertiliser savings for farmers due to enhanced pasture utilisation from SBAS-enabled virtual fencing.

PV$577m in fuel and labour savings for mining haul trucks due to faster speeds enabled by more accurate collision avoidance systems.

Reduction in spraying overlaps from greater penetration of precision spraying within the horticulture and broadacre sectors resulting in **PV$310m** in benefits.

PV$277m in benefits from 45 fatalities and 2,800 serious injuries avoided from the support of enhanced co-operative intelligent transport systems.

1,700 falls from height serious injuries avoided due to the use of enhanced geo-fencing in the construction sector resulting in **PV$224m** in benefits.

PV$168m operating expenditure savings for a port operator from reduced time taken to complete post-processing of hydrographic surveying data in harbour environments.

PV$136m in benefits from 11 million rail maintenance crew labour hours saved due to faster detection of network defects from enhanced geo-referencing capability.

Reduction in flight delays and diversions, resulting in **PV$68m** in benefits, along with enabling larger aircraft and medivac flights into remote rural areas.

Key findings

This Economic Benefits Report analyses the economic benefits of the SBAS signals across 27 Demonstrator Projects, representing 10 sectors involved in the SBAS Test-bed Demonstrator Trial.

Based on considerable research and discussion with Demonstrator Projects, sector participants, and government entities, as well as the outputs from EY's microeconomic analysis of anticipated economic benefits, the following findings have been drawn:

- **The present value (PV) across all sectors is anticipated to be $7.6b over a 30-year period.** Agriculture (29 percent), resources (21 percent), construction (17 percent), and road (14 percent) appear to benefit the most from deployment of an operational SBAS. A sensitivity analysis reflects lower bound and upper bound benefits of between $5.6b and $10.8b.
- This analysis demonstrates that despite the four aforementioned sectors representing 81 percent of the total benefits, **all sectors stand to gain tangible benefits from the deployment of SBAS**. This supports the view that SBAS has potential as a public good offering from governments.
- **The three SBAS signals have performance characteristics that appeal to different sectors.** For example, L1 and DFMC are expected to be the two SBAS signals most relevant for the aviation and consumer sectors. PPP, however, may have greater application in the utilities sector.
- **In total, L1 and DFMC are anticipated to accrue $5.58b and PPP $5.28b in economic benefits over a 30-year period.** This analysis also demonstrates that each of the three SBAS signals trialled **offer a similar level of benefit** to the Australian and New Zealand economies.
- Each sector represented in the Demonstrator Trial has identified that applications for **the SBAS signals will generate significant operational efficiencies and/or improve either health and safety outcomes.**
- The spread of benefits across Australia and New Zealand shows that **the benefits of the SBAS signals are material to both geographies**. This supports the potential for investigation of a regional service and a shared approach to delivery.

It is important to stress that this economic assessment is fundamentally based on the 27 Demonstrator Projects that participated in the Demonstrator Trial.

Therefore, while the findings of this analysis represent anticipated economic benefits to each sector, this assessment does not constitute the full quantum of benefits that could be expected to accrue. This quantum would likely be considerably larger if all potential benefits are considered.

Executive summary

Purpose

This report for the Satellite-Based Augmentation System (SBAS) Demonstrator Trial (Economic Benefits Report) presents the findings of an 18-month investigation into the potential economic benefits anticipated from the deployment of an operational SBAS across Australia and New Zealand over a 30-year period.

The underlying information for this Economic Benefits Report has been drawn from the activities of the SBAS Test-bed Demonstrator Trial – a project focussed on demonstrating and assessing the benefits of an operational SBAS for Australia and New Zealand.

There is an important difference from previous economic studies in that the economic benefits of the SBAS signals presented in this Economic Benefits Report are not based purely on hypothetical assessments of productivity improvements, but also combine the results of on-the-ground testing of the SBAS signals.

This Economic Benefits Report encapsulates the cumulative effort of FrontierSI, EY, 27 Demonstrator Projects, and numerous government and sector stakeholders. These stakeholders collectively identified, conducted, and validated the research necessary to defensibly analyse the anticipated benefits of the SBAS signals.

What is SBAS?

SBAS is a correction service for standalone Global Navigation Satellite System (GNSS) observations and has been implemented in several countries around the world, including the United States, India, Europe, and Japan. In general terms, the SBAS signals provide a service for improving the accuracy, integrity, and availability of standalone GNSS signals (what is commonly referred to in Australia and New Zealand as a Global Positioning System (GPS), which identifies the US GNSS).

Increased accuracy is achieved through the use of correction signals (i.e. the SBAS signals), which are derived from data collected from a ground reference station network. Correction data can reduce the positioning error from standalone GNSS signals from between five and ten metres to decimetre accuracies.

An operational SBAS transmits the correction signals via satellite, as opposed to a terrestrial communications channel, enabling it to cover a wider geographical area.

What is the SBAS Demonstrator Trial?

The SBAS Demonstrator Trial tested the SBAS signals over the past 18 months, with FrontierSI (formerly the CRC for Spatial Information) evaluating their effectiveness and application across 10 sectors through 27 Demonstrator Projects. The SBAS signals include:

Single frequency SBAS (L1)

The L1 signal is the standard service used by various SBAS around the world, such as the US Wide Area Augmentation System (WAAS) and European Geostationary Navigation Overlay Service (EGNOS) and uses the GPS constellation as the basis for its correction signals. L1 SBAS can improve standalone GNSS positioning from five to ten-metre accuracy to sub-metre.

Dual Frequency Multi-Constellation SBAS (DFMC)

DFMC provides an improvement to L1 SBAS in that it utilises both the L1 and L5 signals from two or more satellite constellations (e.g. GPS and Galileo). The DFMC signal is a second-generation technology, and Australia and New Zealand are the first countries in the world to gain access to and test it.

Precise Point Positioning (PPP)

PPP is a method that provides highly accurately position solutions with accuracy of approximately 10 to 20 centimetres once the solution has converged to its optimum level.

Approach to assessing economic benefits

EY was commissioned by FrontierSI to work alongside them, and the 27 Demonstrator Projects, to assist in determining the economic benefits of the SBAS signals.

The development and execution of the Demonstrator Trial has been delivered in a collaborative partnership between Geoscience Australia (GA), Land Information New Zealand (LINZ) and FrontierSI. It represents a significant undertaking that has both trialled the effectiveness of the SBAS signals in the field and has also directly informed this economic assessment.

The analytical approach deployed by EY was fundamentally a microeconomic assessment. The basis for this assessment was first to quantify the benefits anticipated by individual Demonstrator Projects, second scale each benefit up to represent the entire sector (and apportioning both Australia and New Zealand geographies), before finally summing all relevant benefits to provide an estimate of the potential scale and magnitude of directly attributable economic benefits.

In total, 44 quantitative economic benefits across nine sectors have been identified while 30 qualitative benefits have been identified across 10 sectors. At the conclusion of this Economic Benefits Report, 61 additional applications have been identified, however, insufficient evidence was provided to undertake a formal qualitative or quantitative assessment of these benefits.

It is also important to note that Geoscience Australia received funding in the Australian Government's 2018–19 Budget to build and implement an operational SBAS. The Australian SBAS will include a safety-of-life certified L1 service, a DFMC service and a PPP service.

The remainder of this Executive Summary describes the findings of the quantitative microeconomic assessment.

Benefits by sector

Total benefits of **PV AUD$7.6b** are anticipated across the Australia and New Zealand economies from the deployment of the SBAS signals – L1, DFMC, and PPP – over a 30-year period.

As shown in Figure 1, agriculture (29 percent), resources (21 percent), construction (16 percent), and road (14 percent) stand to benefit the most from deployment of an operational SBAS based on those Demonstrator Projects analysed as part of SBAS Test-bed Demonstrator Trial. Table 1 then provides a summary of all benefits by sector.

Figure 1 – Anticipated quantitative economic benefits, by sector

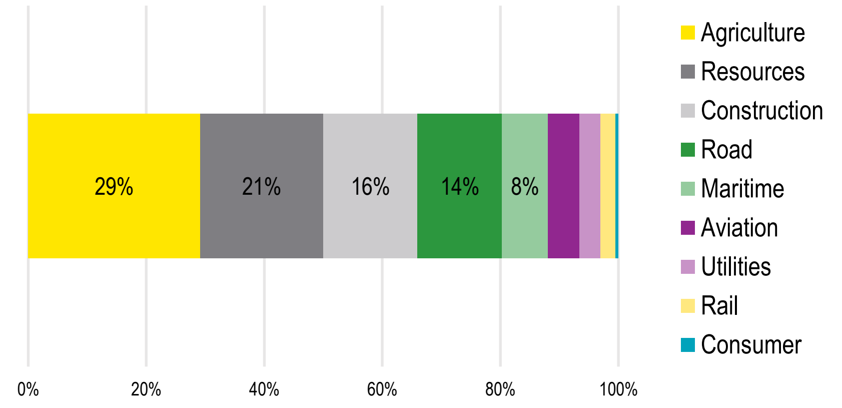


Table 1 – Anticipated quantitative economic benefits, by sector (30-year, AUD)

Sector	Benefits (AUD)
Agriculture	$2.2b
Aviation	$404m
Construction	$1.2b
Consumer	$34m
Maritime	$590m
Rail	$190m
Resources	$1.6b
Road	$1.1b
Spatial	N/A
Water utilities	$280m
Total	**$7.6b**

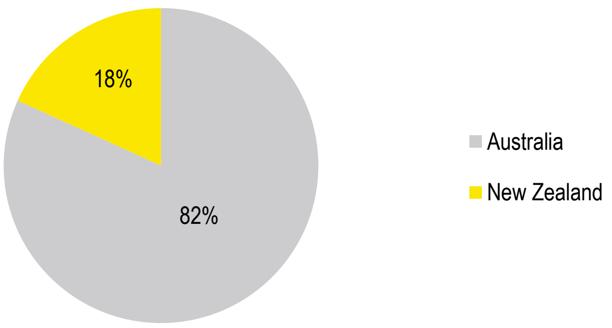
Note: Totals may not sum due to rounding

This study demonstrates that all sectors expect to see tangible benefits from the deployment of the SBAS signals. The SBAS signals are non-rivalrous, as they do not reduce in availability as people consume it, and can be non-excludable, as they are accessible by all. Such widespread adoption therefore suggests the potential of the SBAS signals as a public good offering from the government.

Benefits by geography

Figure 2 shows that approximately 82 percent of benefits are anticipated to accrue to Australia and 18 percent to New Zealand, representing a ratio of roughly four to one in terms of benefits accrued. This represents benefits of **PV AUD $6.2b** to Australia and **PV AUD $1.4b** to New Zealand over the 30-year assessment period.

Figure 2 – Economic benefits by geography



The spread of benefits across Australia and New Zealand shows that the benefits of the SBAS signals are material to both geographies and that they are not unduly disproportional to one country over another on a per population basis (New Zealand has roughly 15 percent of the Australian population).

Importantly, the distribution of benefits across sectors differs between the two geographies. The resource and agriculture sectors accrue the greatest benefits (48 percent) within the Australian economy, whilst the agriculture sector accrues the greatest benefit by far (57 percent) within the New Zealand economy. This can be shown in Figures 3 and 4.

What the data highlights is that contrary to common belief, the agriculture sector is a big winner from the deployment of an operational SBAS.

Figure 3 – Australian benefits by sector

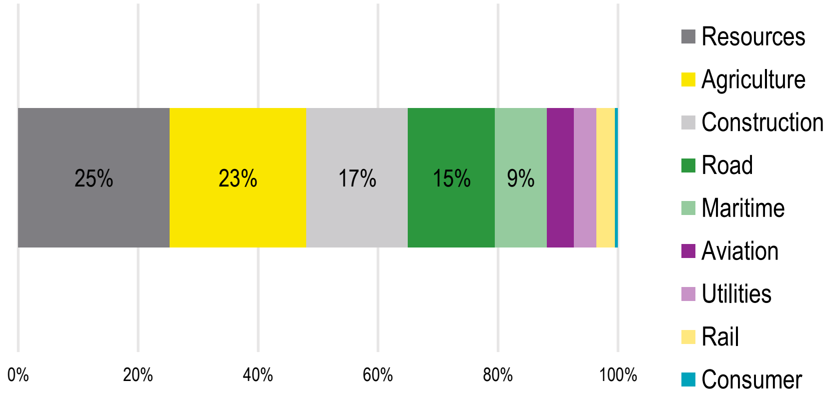
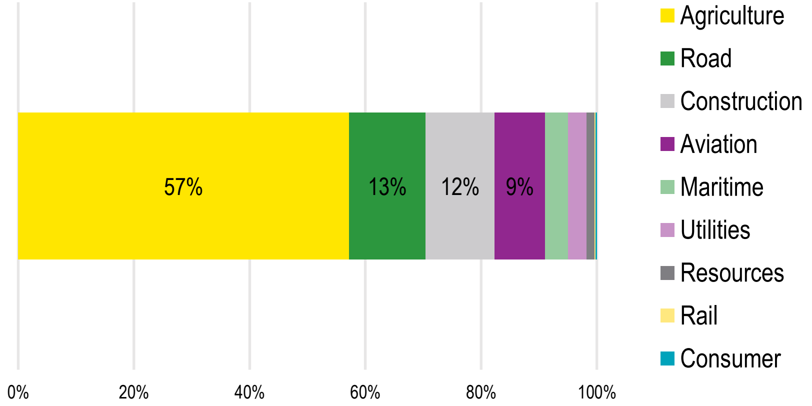


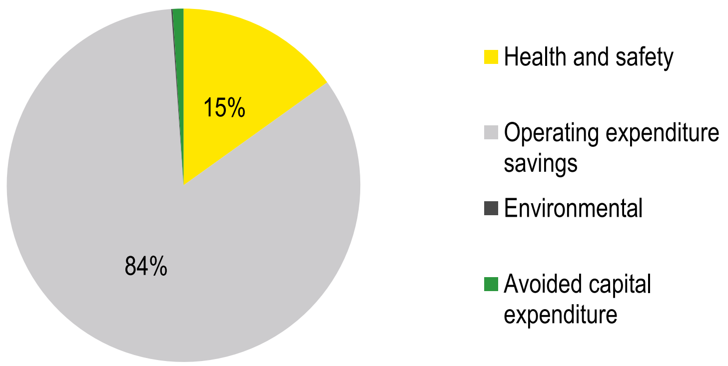
Figure 4 – New Zealand benefits by sector



Benefits by benefit category

As outlined in Figure 5, operating expenditure savings (84 percent) and health and safety (15 percent) have the greatest representation across the quantified benefit categories, which corresponds to the main themes identified from discussions with Demonstrator Projects and the wider sectors covered in this analysis.

Figure 5 – Economic benefits by benefit category



There are two additional observations from this analysis that are important to clarify.

The first is that the nature of the quantitative assessment is such that there is inherent conflation between benefit categories and this is most obvious when considering the relationship between operating expenditure savings and environmental savings.

For example, in a scenario where reduced fuel consumption is possible through the SBAS signals, this has been captured as a reduced operating expenditure benefit as it is the direct result of the benefit. However, it is also expected that this would result in reduced greenhouse gas emissions.

In this sense, it is slightly misleading to attribute all the quantifiable economic benefits to operational savings alone. Rather, it is expected that there will be many flow-on implications (particularly for environmental and possibly for reduced health and safety) that is likely to be significantly under-represented in this quantified analysis.

The second observation is that, more broadly, environmental benefits, health and safety benefits and avoided capital expenditure benefits are all under-represented in the quantitative analysis.

While the perceived quantifiable benefits of these three categories is low (16 percent of total benefits) these categories are more strongly represented once qualitative benefits are contemplated.

Chapter 19 demonstrates that while operating expenditure savings is still the dominant benefits category (73 percent), the total count of these three other categories (once quantitative and qualitative benefits are tallied) is 27 percent.

Benefits by signal

L1 and DFMC are anticipated to accrue **PV AUD $5.58b** in economic benefits and PPP will accrue **PV AUD $5.28b** in benefits over a 30-year period. This reflects the proportion of total benefits attributable to each of the SBAS signals, noting there are overlaps where benefits are attributable to all three signals.

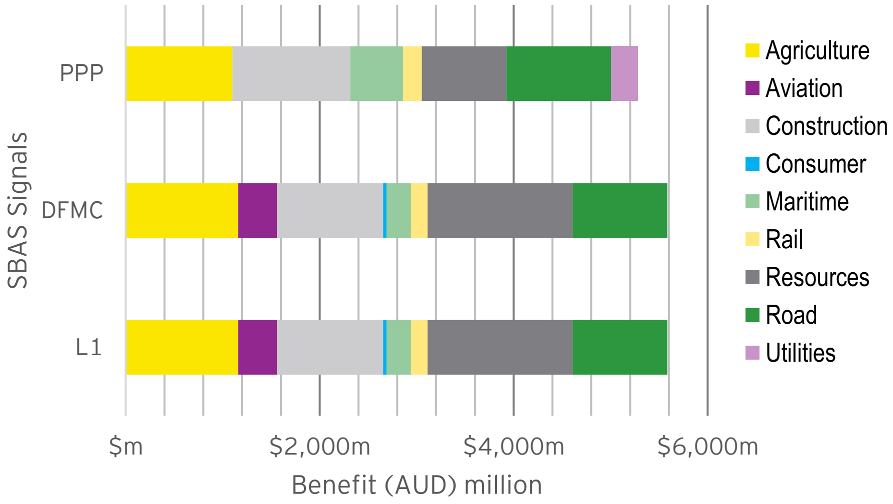
On the face of it, these results imply that there are not major differences between the signals in practice. This is not the case. Figure 6 shows that there is likely to be significant sectoral differences in terms of signal uptake.

L1 and DFMC are anticipated to play a comparably stronger role in the resources sector than PPP and are anticipated to be the sole SBAS signals relevant for the aviation sector.

PPP, however, is anticipated to play a comparably stronger role in the construction, maritime, utilities and rail sectors.

Chapter 19 further demonstrates the anticipated economic benefits by signal type.

Figure 6 – Economic benefits by signal type, by sector (30-year, AUD)



L1 and DFMC are assumed for modelling purposes to provide a similar level of positioning performance and therefore share the same attribution rates throughout this analysis.

Moreover, it is important to note that there are significant overlaps between the signals when calculating the economic benefits. This is the reason that the bars in Figure 6 do not sum to the $7.6b total. The signal attribution methodology is described in more detail in Chapter 4.4.3.

Sensitivity testing

As noted throughout this Economic Benefits Report, a range of assumptions have been made to develop reasonable models of the potential economic benefits of the SBAS signals across multiple sectors. These assumptions have been developed through rigorous desktop research and have benefitted from significant consultation with sectors and experts to ensure they reflect reality.

Sensitivity testing of these values has been completed to demonstrate the potential scale of economic benefits under different assumptions. Alternative discount rates have been applied to complete this testing.

It is acknowledged that use of discount rates for sensitivity testing may be considered a blunt instrument; however, sensitivity testing of uptake rates and other input variables is complicated and highly subjective (for example, what variables to test, to what extent, over what time-period, and who decides what to use).

Given the desire to generate consensus behind all elements of this analysis, it was decided not to sensitivity test to this level of granularity. Discount rate sensitivities are, however, considered appropriate to determine order and magnitude of potential benefits under different world views.

The following discount rates have been applied across each sector result as demonstrated in Table 2.

- 8.5 percent (assumes a lower level of confidence in the findings)
- 6.5 percent (discount rate used in modelling)
- 4.5 percent (assumes a higher level of confidence in the findings).

Table 2 – Sensitivity testing, by sector (30-year, AUD)

Sector	**Discount rate sensitivities**		
	4.50%	**6.50%**	**8.50%**
Agriculture	$3,193m	$2,206m	$1,567m
Aviation	$485m	$404m	$313m
Construction	$1,718m	$1,213m	$879m
Consumer	$49m	$34m	$24m
Maritime	$755m	$588m	$470m
Rail	$281m	$193m	$135m
Resources	$2,295m	$1,581m	$1,115m
Road	$1,600m	$1,084m	$753m
Water utilities	$398m	$277m	$197m
Total	**$10,773m**	**$7,581m**	**$5,454m**

What this sensitivity testing shows is that even under pessimistic scenarios of expected SBAS signal uptake, the economic benefits are still material and accrue across all sectors of the economy.

1. Introduction

Between 2017 and 2019, Geoscience Australia (GA) and Land Information New Zealand (LINZ) funded FrontierSI, formerly the Cooperative Research Centre for Spatial Information (CRCSI), to trial an operational Satellite-Based Augmentation System (SBAS) and assess the economic benefits of three SBAS signals for Australia and New Zealand.

The term operational SBAS refers to the entire SBAS consisting of reference stations, master stations, communication satellites, and the broadcast SBAS signals. The SBAS signals for the purposes of this Economic Benefits Report is the term used to collectively refer to the three signals being trialled: a single frequency SBAS (L1), Dual Frequency Multi-Constellation SBAS (DFMC); and Precise Point Positioning (PPP).

The SBAS Test-bed Demonstrator Trial (the Demonstrator Trial) trialled the SBAS signals across 27 Demonstrator Projects, representing 10 different sectors: agriculture, aviation, consumer, construction, maritime, rail, resources, road, spatial, and water utilities across the Australian and New Zealand economies.

The Demonstrator Trial is a significant contribution to the collective knowledge of the applicability of an operational SBAS in Australia and New Zealand. The intention of the Demonstrator Trial is to enable policy makers to understand the performance of the SBAS signals across a variety of environments and determine whether the benefits anticipated across the economy would be achievable based on actual testing results.

EY's role in the Demonstrator Trial has been to undertake an economic benefits assessment of the SBAS signals based on the outputs of the Demonstrator Projects, drawing on newly gathered knowledge, data, and expertise for their respective sectors as well as previous analyses[1]. EY designed a process and methodology, and undertook the necessary quantitative and qualitative assessments to provide an indication of the scale and magnitude of these likely economic benefits.

The full scope of services is detailed in the services agreement that commenced on 18 September 2017.

1.1 Purpose the Economic Benefits Report

This Economic Benefits Report for the SBAS Demonstrator Trial (Economic Benefits Report, this report) represents the culmination of 18 months' work.

The purpose of the Economic Benefits Report is to present an estimate of the potential economic benefits, both quantitative and qualitative, derived from the deployment of an operational SBAS across Australia and New Zealand. This report presents benefits anticipated from all 27 Demonstrator Projects involved in the Demonstrator Trial and assesses each benefit based on information and evidence provided at the time of writing.

This report encapsulates the cumulative effort of FrontierSI, EY, Demonstrator Projects, and numerous government and sector stakeholders to identify, obtain, and validate research and data necessary to quantify the benefits anticipated. Well over 200 stakeholder interviews and 200 reference points have been utilised in producing this report.

1.2 Report structure

Chapter 1 of this Economic Benefits Report introduces the Demonstrator Trial, details the report structure and provides an overview of challenges and mitigations associated with this analysis.

Chapter 2 provides an overview of an operational SBAS and the accompanying SBAS signals, while Chapter 3 provides further detail around the Demonstrator Trial.

Chapters 4 and 5 outline the approach deployed for this analysis, while Chapter 6 summarises the overall economic benefits of SBAS based on the cumulative findings of the sector Chapters.

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[1] Examples include:

- ACIL (2011) Economic benefits of high resolution services. Retrieved from: http://www.crcsi.com.au/assets/Resources/ffa927a7-55d1-400a-b7d6-9234f4fe4ad2.pdf
- ACIL (2013) The value of augmented GNSS in Australia. Retrieved from: http://www.acilallen.com.au/cms_files/ACIL_GNSS_positioning.pdf
- Castalia Strategic Advisors (2015) Economic analysis for the aviation sector of the proposed satellite-based augmentation system.

Chapter 7 provides an overview of the structure of each sector Chapter, while Chapters 8 to 17 comprise the most substantive part of this Economic Benefits Report and contain the findings of the analysis on a sectoral basis. This sector-by-sector analysis was considered appropriate because of the uniqueness of each sector as well as the high levels of overlap in presenting benefits across Demonstrator Projects within each sector.

Each sector Chapter can be read as a standalone document, or as part of the Economic Benefits Report, and has gone through a rigorous review cycle with all relevant Demonstrator Projects, sector participants, and relevant government agencies.

It is also worth stressing that each sector Chapter has been strongly informed by the relevant Demonstrator Project(s) and accompanying sector participant(s) to ensure the content contained is relevant for the sector.

Additionally, FrontierSI has provided technical and logistical support to ensure the deployment and capabilities of the SBAS signals is interpreted correctly. EY has provided economic support by providing guidance to Demonstrator Projects and sector participants around how potential benefits could be quantified.

Chapter 18 details additional applications which may benefit from an operational SBAS but are not captured in this analysis.

Finally, Chapter 19 summarises the economic benefits on a line-by-line basis and a comprehensive bibliography is provided in Appendix 1.

Fundamentally, this Economic Benefits Report should be viewed as a covering report, which aims to aggregate and harmonise the findings of each sector Chapter, to provide a coherent economy-wide view of the benefits of an operational SBAS.

1.3 Challenges and mitigations

The fundamental premise of this analysis requires an assessment about potential uptake of a new technology. This creates many analytical challenges that are important to identify. A brief description about how these limitations have been mitigated (to the extent possible) through the methodological approach, is provided below.

Applications captured

An analogy commonly used throughout the Demonstrator Trial is that assessing the economic impact of the SBAS signals is akin to quantifying the benefits of the internet during its early stages. Inherent in such economy-wide, transformative technologies is the ability to impact on a wide variety of sectors, and operations, in ways which are known and unknown at the time of analysis.

The focus of this Economic Benefits Report is on those applications which are known and explicitly identified as part of the Demonstrator Trial.

However, throughout this project EY has come across numerous applications which stand to benefit from the SBAS signals but have not been included as part of this Demonstrator Trial – these are referred to as the known unknowns. Chapter 18 of this Economic Benefits Report has attempted to collate a list of these known unknowns to show the likely scale of benefits that this analysis has not accounted for, due to time, scope, data availability, and analytical confidence constraints.

Lastly, it is acknowledged there are current and future applications that those involved in this project have not even thought about – the unknown unknowns. Whilst it is difficult to gauge the size of potential economic benefits from these unknown applications, it must be acknowledged that they exist.

Adoption scenarios

Another challenge associated with transformative technologies is attempting to understand uptake rates. It is not the presence of the SBAS signals that enables benefits to accrue, but rather the propensity for parties to adopt the technology once it is made available.

As a basis, it is assumed that no sector will experience full adoption from day one; however, understanding how uptake will occur over a 10, 20, and 30-year period can vary significantly from sector to sector.

EY asked sector experts to provide their view on uptake within the sector and researched similar transformative technologies within respective sectors to calibrate uptake curves as part of the modelling exercise.

As shown in Figure 7, uptake curves[2] as part of this analysis have taken on one of four styles: linear, exponential, S-curve, or logarithmic. All economic benefits have also experienced different maximum uptake rates that range

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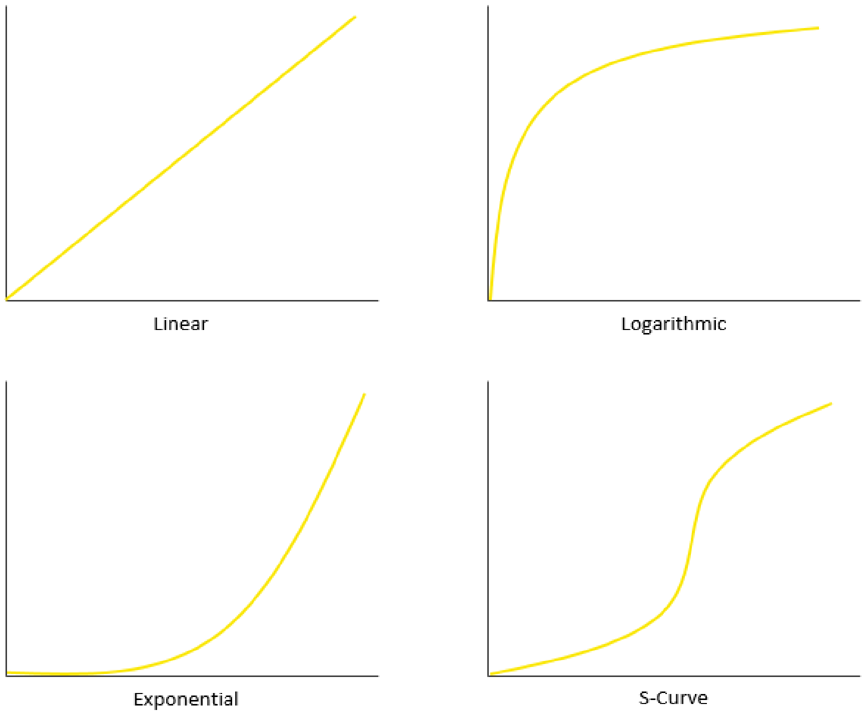
[2] An uptake curve in this context is representative of the forecast uptake rate of the SBAS signals over a 30-year period. It is not always strictly a 'curve'.

from 18 to 100 percent uptake at the end of the assessment period. Any deviation from these curves is a result of extraordinary sector-specific uptake.

Figure 7 – Uptake curve types



Demand elasticities

Demand elasticity refers to how sensitive the demand for a good is to changes in other economic variables, such as prices and consumer income[3]. Inherent in the deployment of uptake curves, is an assumption around the likely responsiveness of consumers to the benefits of the SBAS signals.

It is important to stress that an assessment of elasticity curves for each anticipated benefit has not been completed. However, where possible potential responsiveness of sectors to the introduction of the SBAS signals has been calibrated using sector expertise from the Demonstrator Projects, or using studies and research on similar transformative technologies.

Scaling

Scaling has been undertaken in many instances to understand the anticipated benefits of a Demonstrator Project across the wider sector it represents and to understand the benefits that can accrue to its geographical counterpart in either Australia or New Zealand.

The main issue when it comes to scaling is the degree of applicability. For example, how applicable is the reduction in spray overlaps within the apple sector to the wider fresh fruit sector? How applicable are dairy productivity improvements from virtual fencing in Australia, to New Zealand?

In attempting to answer such questions, EY typically sought the views of a given Demonstrator Project before widening the sphere of input to relevant industry bodies, sector experts, and government agencies to help gauge applicability of benefits as a matter of principle. The outputs of those conversations, and data and evidence provided, have been used to calibrate scaling factors.

Signal performance and attribution

A key consideration in the economic analysis process is the actual performance of the SBAS signals through the Demonstrator Trial.

In simple terms, anticipated economic benefits represent the directly attributable economic benefits that could accrue assuming the SBAS signals meet performance criteria. This performance criteria differed from project to project, although accuracy was a common determinant of economic benefit. Conversely, should the SBAS signals fail to meet positioning thresholds for a given application, economic benefits were not presented.

This concept applies to each of the three SBAS signals trialled – L1, DFMC and PPP.

FrontierSI took the lead in consolidating the results from the Demonstrator Trials, to establish the final performance levels across each of the signals. These findings, along with the rationale surrounding EY's attribution process, is further elaborated in Chapter 4 (and results included in each sector Chapter).

Note that all positioning accuracy figures stated throughout this report and all sector Chapters should be assumed to refer to horizontal accuracy at a 95 percent confidence interval unless stated otherwise.

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[3] https://www.investopedia.com/terms/d/demand-elasticity.asp

Stakeholder consensus

Benefits within a sector, specifically those at the cutting edge of technology, are often subject to differing views around the scale and nature of their impact. For example, in the case of connected and automated vehicles (CAVs), views ranged from an expectation of a regulatory mandated implementation of the SBAS signals in all CAVs, to no role at all due to the prevalence of alternative competing technologies.

In such instances, significant effort has been made to engage with a range of sector experts to gather an informed position on the impact of the SBAS signals, off the back of which economic benefits can be analysed.

Everything contained with this Economic Benefits Report is viewed as being appropriate for the completion of this report, with outputs and assumptions being approved by relevant Demonstrator Projects and content sighted and challenged by selected industry participants and relevant government agencies.

Data limitations

Where possible, effort has been made to source data underpinning benefit analysis from empirical sources, government resources, or statistical data.

In instances where this has not been possible, this analysis has relied on and cited the sector expertise of Demonstrator Projects and sector participants and is referenced accordingly.

Owing to confidentiality concerns, specific Demonstrator Projects have generally not been cited, rather a general reference has been included citing information being provided by a Demonstrator Project.

Differing audiences

A final challenge in producing this Economic Benefits Report has been the desire to produce a report that balances the expectations of a diverse readership.

Fundamentally, this Economic Benefits Report has benefitted from true technical experts in their given field and this sometimes means that the level of information provided was far more detailed that could be comprehended by a common audience.

This Economic Benefits Report fundamentally tries to balance the desire to present information that satisfies the evidential expectations of Demonstrator Projects with the need to be readable to a wider audience. In practice this may mean that certain concepts have been simplified in the name of conciseness and readability. This does not detract from the complexity that underpins an operational SBAS or the operations of potential users.

2. Understanding an operational SBAS

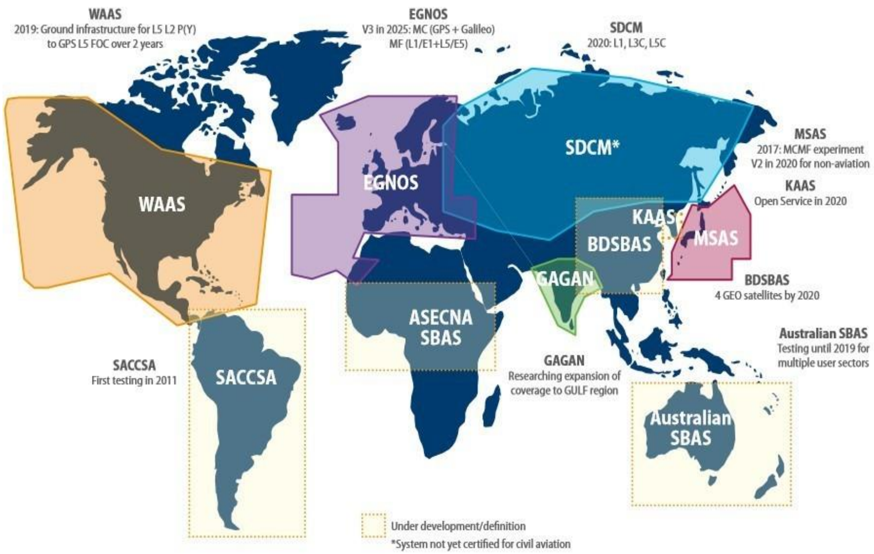
In developing a methodology appropriate for the assessment of economic benefits attributable to the SBAS signals, it is vital to understand the capabilities of an operational SBAS and the general benefits it offers relative to its counterparts.

2.1 What is an operational SBAS?

An operational SBAS is a correction service for standalone Global Navigation Satellite System (GNSS) observations and has been implemented in several regions around the world, including the United States, India, Europe, and Japan.

Figure 8 shows the operational SBAS services available in the northern hemisphere and those being trialled in the southern hemisphere.

Figure 8 – Geographic examples of utilisation of SBAS technology[4]



The concept of an operational SBAS was originally created as a navigation safety measure for the aviation sector; however, benefits to other sectors became apparent soon after.

In general terms, an operational SBAS provides a service for improving the accuracy, integrity, and availability of standalone GNSS, or what is traditionally known as Global Positioning System (GPS) in Australia and New Zealand (due to use of the US GNSS system).

Increased accuracy is achieved using correction signals (referred to as the SBAS signals) which are derived from data collected from a ground reference station network. Correction data can reduce the positioning error from standalone GNSS signals from between five to ten metres to decimetre accuracies. An operational SBAS transmits this correction signal via satellite, as opposed to a terrestrial communications channel, enabling it to cover a wider geographical area.

An operational SBAS typically includes multiple reference stations, one or more master stations and one or more communications satellites.

Reference stations

Operational SBAS reference stations receive GNSS signals and transmit these signals to the master stations for processing, analysis and generation of correction and integrity messages.

Master stations

By collecting raw GNSS data from a network of reference stations, master stations can calculate wide-area corrections and then uplink the correction signal to an operational SBAS satellite.

Communications satellites

Such satellites are used to transmit the correction signal(s) across a region to (a theoretically unlimited) number of receivers.

Each component works together to provide a robust system which offers high levels of signal accuracy, availability, and integrity.

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[4] European Global Navigation Satellite Systems Agency (2018) GNSS user technology report: issue 2. Retrieved from: https://www.gsa.europa.eu/system/files/reports/gnss_user_tech_report_2018.pdf

Internationally, each operational SBAS has traditionally been deployed using a single frequency, L1. A unique feature of this Demonstrator Trial is the testing of the DFMC signal as well as the PPP signal. These signals are detailed below.

Single frequency SBAS (L1)

Standalone GNSS establishes the position of an object by measuring simultaneous distances to four or more satellites, whose positions are precisely known.

The L1 signal is the standard service used by various operational SBAS' around the world and uses the GPS constellation as the basis for its correction signals, which can improve standalone GNSS from five to ten metre accuracy down to sub-metre level. The L1 signal is the only service certified for safety-of-life operations.

Dual Frequency Multiple Constellation SBAS (DFMC)

DFMC provides an improvement to traditional L1 SBAS in that it utilises two frequencies from two or more satellite constellations (e.g. GPS and Galileo), whilst also requiring considerably less ground infrastructure. This means a receiver has access to more GNSS satellites at any given time and an enhanced capability to eliminate the influence of the ionosphere (part of the upper atmosphere), thereby increasing its ability to maintain sub-metre accuracies.

The DFMC signal is a second-generation technology and Australia and New Zealand are the first countries in the world to gain access to and test it. It is important to note that not all existing receivers are equipped to utilise DFMC. Based on the discussion with FrontierSI, it is anticipated that DFMC performance will improve over time as receivers improve to better accommodate this new signal.

Precise Point Positioning (PPP)

PPP is an absolute positioning method that provides highly accurate position solutions, down to decimetre level. It works by applying precise satellite orbit and clock corrections which can reduce the errors affecting GNSS positioning. While the PPP method is superior compared to SBAS in terms of accuracy, it suffers from long convergence times relative to the instantaneous positioning availability of L1 and DFMC solutions. With the PPP method, the positioning starts at around a metre-level and converges down to decimetre level over time. Typical convergence time required to achieve this accuracy ranges from 40 to 60 minutes and if the satellite lock is lost, then re-convergence is required. As PPP technology develops further, there is potential for convergence times to reduce.

Also, unlike SBAS that can be used on any GNSS device, PPP requires special hardware including specialised GNSS chipsets and a subscription to a correction service. This imposes cost barriers that are higher than L1 and DFMC. More information about price sensitivities of PPP hardware is provided in Table 5.

Whilst, dual-frequency chipsets are starting to be introduced on mobile phones, it is anticipated that in the future PPP positioning could also be incorporated into mobile phones.

The various Demonstrator Projects listed in Chapter 3 have tested one, two or all the SBAS signals depending on their specific needs.

In addition, this analysis has sought not only to determine the overall benefits of the SBAS signals, but to ascertain the incremental benefits afforded by each signal, across both Australia and New Zealand. This incremental analysis should help guide policy decisions around optimal investment in signal infrastructure within each country.

2.2 General benefits of an operational SBAS

An operational SBAS generates a series of potential positioning benefits that will be identified across various Demonstrator Projects. Critical benefits include:

Expanded coverage of augmented positioning

An operational SBAS utilises satellite communications to convey correction and integrity data to users as opposed to the terrestrial communications infrastructure used by most other position augmentation methods. Therefore, data can be transmitted across a wider coverage area as an operational SBAS but is not bound by the limited transmission radius of terrestrial mobile communications. It can therefore be used in geographically remote and offshore areas.

Enhanced accuracy of position

An operational SBAS utilises a network of ground-based reference stations to compute corrections for systematic biases affecting GNSS, thus enabling decimetre level positioning accuracy compared to the five to ten metre accuracy of standalone GNSS.

Signal integrity component

Certified L1 and DFMC signals contain an integrity component, which meets safety-of-life standards set by the International Civil Aviation Organisation (ICAO) and protects users from failures of GNSS satellites and transmissions of erroneous differential corrections. DFMC signals are expected to meet future ICAO standards once they are developed and implemented.

Increased signal redundancy

Redundancy refers to having extra capacity which can serve as a backup or enhance the quality of GNSS. The SBAS signals provide redundancy by enabling methods such as Real Time Kinematics (RTK) to revert to sub-metre position accuracy instead of standalone GNSS, in instances when the core positioning system goes down.

Reduced cost for access to enhanced positioning signals

The SBAS signals represent an alternative to commercial positioning services, which sometimes require specialist equipment and subscription costs to private operators, as well as non-commercial positioning services. Signals are also expected to be provided free of encryption which means they exhibit public good characteristics.

Reduced cost of investment in positioning infrastructure

An operational SBAS uses satellite communications for regional coverage and requires less terrestrial infrastructure, thereby reducing the operational and capital costs associated with positioning infrastructure relative to other regional positioning methods.

The general benefits result in either operational improvements to users (from the status quo) or they enable new markets, products, or sources of revenue to be generated by individual firms, sectors, or the economy.

2.3 Prior studies

An operational SBAS, and the broader area of precise positioning, has been the focus of numerous studies over the years. In an Australian and New Zealand context, three studies stand out:

Allen Consulting Group's 2008 Economic benefits of high resolution positioning services[5] study was one of the first studies to explore the potential economic benefits of high resolution positioning services in the Australian economy, with a focus on the mining, agriculture and civil engineering/construction sectors. It is important to note that this report focussed on a range of GNSS augmentation services, but not specifically on an operational SBAS.

The study found that when applied to these sectors, precision GNSS had strong prospects to produce considerable future benefits of up to AUD $12.6b (in 2008 dollars) by 2030.

Booz (2009) undertook a specific review of an operational SBAS to determine the efficacy of an Australian SBAS capability within the aviation sector. The main finding of the review was that it was difficult to justify funding an operational SBAS in Australia solely based on aviation operations at smaller aerodromes. These findings were supported by the 2013 The value of augmented GNSS in Australia[6] report by ACIL Allen Consulting, which concluded that the net benefits of an SBAS to the aviation sector alone do not appear to be sufficient to justify the cost.

Castalia Strategic Advisors undertook a cost benefit analysis in 2015 for the use of an operational SBAS in the New Zealand aviation sector, titled Economic Analysis for the Aviation Sector of the Proposed Satellite-Based Augmentation System[7]. Their work showed that overall costs outweighed benefits; however, they noted that there would certainly be some benefits to other sectors and that the benefits would likely help bridge the gap between costs and benefits for aviation.

In addition to these studies, there have been numerous other studies on the benefits of an operational SBAS to specific sectors, some of which are included in Appendix 1.

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[5] Allen Consulting Group (2008) Economic benefits of high resolution positioning services. Retrieved from: https://www.crcsi.com.au/assets/Resources/ffa927a7-55d1-400a-b7d6-9234f4fe4ad2.pdf

[6] ACIL (2013) The value of augmented GNSS in Australia. Retrieved from: http://www.acilallen.com.au/cms_files/ACIL_GNSS_positioning.pdf

[7] Castalia Strategic Advisors (2015) Economic analysis for the aviation sector of the proposed satellite-based augmentation system.

3. SBAS Demonstrator Trial

3.1 Project description

The Demonstrator Trial was designed to achieve three main objectives:

Assess current and future operational SBAS technology directly in many sectors

Unlike previous studies, the Demonstrator Trial provided an opportunity for Demonstrator Projects to physically trial the SBAS signals and where possible, gather empirical evidence to support claims of achievable accuracy and potential economic benefits.

Explore current and future sector-specific requirements and how they interact with the technology

This Demonstrator Trial aimed to assess the specific requirements (including accuracy, integrity, and availability) of each industry sector, before identifying economic benefits attributed to the SBAS signals over and beyond the status quo.

Explore sector innovations that might be borne out by the technology

In addition to benefits to existing processes, this Demonstrator Trial anticipated the SBAS signals to enable the formation of new markets, business opportunities and processes which may lead to large economy-wide benefits for Australia and New Zealand.

Testing of the SBAS signals occurred over an 18-month period, with FrontierSI managing the Demonstrator Projects. Overall, the Demonstrator Trial aimed to support decisions by Australia and New Zealand as to whether they should pursue the development of an operational SBAS.

Infrastructure required for the operational SBAS for this Demonstrator Trial was provided by:

- Inmarsat, who transmitted SBAS signals via its L-Band satellite transmitter on the 4F1 satellite
- Lockheed Martin, who provided the satellite uplink capability via its uplink control station in Uralla, New South Wales (NSW), Australia
- GMV Innovative Solutions, who operated the positioning correction service
- GA and LINZ who operate the ground reference stations across Australia and New Zealand.

The development and execution of the Demonstrator Trial was delivered in partnership between GA, LINZ, and FrontierSI.

3.2 Demonstrator Projects

At the outset of the Demonstrator Trial, FrontierSI called for interested organisations from a range of sectors to participate. Table 3 contains a list of Demonstrator Projects that took part in the Demonstrator Trial, a brief description of each project, and the sectors represented.

The Demonstrator Projects selected provided strong representation across the 10 sectors, which included; agriculture, aviation, consumer, construction, maritime, rail, resources, road, spatial, and water utilities.

While Demonstrator Projects recorded technical information relating to the SBAS signals (accuracy, coverage, reliability, etc) they did so whilst not relying on the technology to make operational decisions. In this sense, the outputs of the economic assessment should be considered an improvement on previous studies and provide a far more technologically robust view of future benefits based on an enhanced evidence base. However, it should be noted that they are still not proven operationally as a standalone technology.

Table 3 – Demonstrator Projects

No.	Sector	Organisation	Abridged project description
1	Agriculture	Corrigin Farm Improvement Group	Crop production using precision positioning
2	Agriculture	CQUniversity Australia	Livestock tracking
3	Agriculture	Forestry Corporation of NSW	Under-canopy forest mapping and harvest vehicle tracking
4	Agriculture	Kondinin Group	Crop production using precision positioning
5	Agriculture	Page Bloomer	Horticulture production using precision positioning
6	Agriculture	Plant and Food Research	Vine production using precision positioning
7	Agriculture	Venture Southland	Forestry mapping for land and forest characteristics
8	Aviation	Airservices Australia	Aircraft navigation
9	Aviation	Airways New Zealand	Aircraft navigation
10	Construction	Position Partners/University of NSW	Engineering machine guidance, personnel tracking, and Unmanned Aerial Vehicle (UAV) navigation
11	Consumer	Australia Post	Automated last mile parcel delivery
12	Consumer	Queensland University of Technology	Visually impaired pedestrian navigation
13	Maritime	Acoustic Imaging/Port Authority of New South Wales	Hydrographic surveying and pilotage
14	Maritime	Identec Solutions	Port operations
15	Maritime	Maritime Industry Australia Limited	Vessel navigation and tracking
16	Rail	Position Partners/TasRail	Locomotive tracking and rail maintenance
17	Resources	Curtin University/Roy Hill	Ore mapping and management
18	Resources	Queensland University of Technology/Wenco International Mining Systems	Mine vehicle tracking
19	Road	Curtin University/Transport for NSW	Implications for co-operative intelligent transport systems (C-ITs)
20	Road	HERE Technologies	Production of high definition road maps
21	Road	Ministry of Transport New Zealand	Real-time road pricing
22	Road	VicRoads	Implications for CAVs
23	Spatial	Department of Finance, Services and Innovation – Spatial Services	Land surveying
24	Spatial	Department of Environment, Land, Water and Planning/Royal Melbourne Institute of Technology	Land surveying
25	Spatial	Orbica/Reveal Infrastructure	Asset mapping
26	Spatial	University of Otago	Land surveying
27	Water utilities	University of Tasmania	Precision agriculture with UAV imagery

3.3 Demonstrator Trial process

At a technical level, there were many unique features of the Demonstrator Trial programme.

3.3.1 Demonstrator Project structure

Each Demonstrator Project had two key components to their project:

- **Testing the SBAS signals**

  Project teams identified various use cases or applications in their sector and developed a test plan and methodology to carry out this testing.

- **Evaluation of the economic benefits**

  Once the cases or applications where the SBAS signals could be utilised were identified, discussions were held with the project team, FrontierSI and EY.

Each Demonstrator Project was different. For example, some Demonstrator Projects started testing as early as October 2017 or as late as February 2019 and project duration ranged from a few months to 12 months. Some projects carried out extensive testing, while others carried out enough testing to be able to demonstrate the applications relevant to the economic benefits discussed in this report. To conduct testing, FrontierSI provided project teams with hardware and technical support so that each project team could access the SBAS signals.

3.3.2 Interpreting the results for the economic study

A critical design feature of the economic assessment was the concept of positioning results meeting performance expectations to ‘unlock’ economic benefits.

Put simply, for each anticipated economic benefit, a certain performance standard was identified in discussion with the Demonstrator Project (and sector experts). If the positioning results of the Demonstrator Project were better than this performance standard, a range of economic benefits would be ‘unlocked’ and EY sought to model these impacts quantitatively (or present them qualitatively). Where these standards were not met, benefits were not unlocked, and modelling did not occur.

Throughout the Demonstrator Trial, several permutations relating to this design concept were seen:

1) The testing results of a Demonstrator Project were sufficiently promising to meet or exceed expected positioning performance standards required for each economic benefit to be unlocked.
2) The testing results of a Demonstrator Project were not sufficiently promising to meet or exceed stated performance standards; however, this is not what could be reasonably expected in practice should an operational SBAS be deployed.
3) The testing results of a Demonstrator Project were not sufficiently promising to meet or exceed stated performance standards, nor would they be even if an operational SBAS was deployed.

Only those benefits that fall into the first two categories were modelled through this study.

3.3.3 General trial limitations

As indicated above, it is likely that an operational SBAS (and the performance of DFMC in particular) within Oceania will show better results than those found during the Demonstrator Trial. This is the primary basis behind the inclusion in the eventual modelling of those benefits noted in bullet point 2 above.

Additionally, it is worth noting that the Demonstrator Trial was limited by the following factors. It is expected that an operational SBAS would address these issues:

GPS and Galileo constellations

Only some satellites in the GPS constellation have L5 capability and whilst L1/L2 GPS was used as a workaround during the Demonstrator Trial, the level of noise in the DFMC solution was increased. Additionally, it is worth noting that the Galileo constellation is yet to be fully operational. Despite this, the number of Galileo satellites increased during the Demonstrator Trial and more satellites will be visible once the system is operational (estimated to occur in 2020). This affects both DFMC and PPP signal results.

Testing infrastructure

The SBAS test-bed infrastructure used was existing infrastructure within the region. Infrastructure used within an operational system is expected to provide a better solution than was seen during the Demonstrator Trial and this is especially relevant for the PPP results.

Additionally, only one satellite – Inmarsat 4F1 – was used within the testing infrastructure. This can mean there are areas where it may not be as visible as a scenario with multiple satellites. Fully operational SBAS' in the world typically have one or more satellites to broadcast the SBAS signals. Having more satellites available can assist with SBAS satellite visibility and can affect all signals broadcast.

Thorough testing and certification

The Demonstrator Trial was testing SBAS as a proof of concept in the Australian and New Zealand region. It did not go through the rigorous testing or certification process an operational SBAS would go through when implemented.

Additionally, the Demonstrator Trial performance improved over the duration of the project as the system was monitored and evaluated. Monthly maintenance for software upgrades occurred in the first half of the project at the master station and further upgrades were available periodically for the prototype receivers used in the Demonstrator Trial.

The combination of existing reference stations was also monitored so that the best information was provided over the entire region.

Ground receivers and hardware

The Demonstrator Projects utilised a variety of hardware, some of which was of a prototypical nature. Except for some SBAS L1 testing which was performed on GNSS consumer devices, every project used this prototype hardware and it is not as reliable, nor potentially as user friendly, as commercial off-the-shelf hardware. In an operational SBAS, users would use consumer-grade hardware.

Despite these factors, all Demonstrator Projects successfully tested the SBAS signals in a variety of applications. In instances where non-ideal results were experienced, tests were often re-run or FrontierSI assisted with troubleshooting to ensure the best results could be achieved.

It is extremely important to note that not all projects achieved ideal[8] results; however, it was expected that not all testing scenarios would achieve ideal results and this does not detract from the validity of the results. This Demonstrator Trial was as close a simulation of the real world, where an operational SBAS exists in the region, as possible.

3.3.4 Specific testing limitations

In addition to the technical limitations to the Demonstrator Trial noted above, there were two main factors which influenced the testing results found by projects: the environment in which testing was conducted and the type of hardware used (including receiver and antenna combinations).

3.3.4.1 Trial environments

The positioning performance of a GNSS system is directly affected by the environment in which it is operated, as objects or structures can obscure sections of the sky or otherwise interfere with the transmission of accurate information to the user. Table 4 defines the range of environmental obstructions on GNSS, which was used in this Demonstrator Trial.

Table 4 – GNSS environmental obstruction definitions

Environment	Definition
Open-sky	No obstructions, highest accuracy results expected
Light obstruction	One storey buildings and some trees, no significant obstructions
Partial obstruction	Two to three storey buildings, medium-level tree canopy, undulating terrain, open mine pits etc.
Moderate obstruction	Dense forest, container port (cranes), construction sites (machinery/equipment) etc.
Significant obstruction	Urban canyon, other significant obstructions

Open-sky environments are defined as areas containing no significant obstructions to the antenna sky view and are expected to achieve the highest accuracy results.

Areas with one storey buildings and some foliage present would be defined as containing a light obstruction and might incur a slight performance reduction.

Areas with two to three storey buildings, medium-density tree canopy, or other challenging conditions such as undulating terrain, or open mine pits, would be defined as containing a partial obstruction. Operating in a partially obstructed environment can be expected to yield reduced positioning

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[8] Ideal in this context refers to results that would be expected if commercial-grade hardware was used.

accuracy. Dense forest, construction sites, or container ports would be considered as examples of these areas.

Moderate obstruction would be when thick canopy or machinery, such as cranes or trucks, could be expected to block sky visibility, resulting in a significant impact on performance.

Areas with tall buildings (such as urban canyons) and overhead structures would be defined as having a significant obstruction, which could result in severely degraded positioning performance, or misleading observations.

3.3.4.2 Demonstrator Trial hardware

GNSS receivers and antennas can be roughly divided into three tiers based on their precision and cost.

Consumer grade GNSS chips such as those found in many mobile phones and trackers generally cost less than $100 and experience significant reductions in performance under obstructed conditions, as well as overall lower precision than either mid-range or professional grade receivers. They typically use consumer-grade patch antennas.

Mid-range receivers and antennas used for mapping, robotics, or machinery tracking can cost up to $3,000, but will be designed to operate in a wider range of environmental conditions and at a higher level of precision than consumer grade receivers.

Professional grade receivers and antennas are more expensive and primarily used in high-precision applications such as surveying and geodesy, where positioning performance is paramount. Table 5 describes the categories of GNSS receivers and antennas used in this Demonstrator Trial.

Table 5 – Categories of GNSS hardware by cost and precision

Category	Definition
Consumer	< $100 – consumer grade chips, mobile phones, IoT, trackers, etc.
Mid-range	$100–$3,000 – GIS, mapping, forestry, robotics etc.
Professional	> $3,000 – geodetic, surveying, high-precision applications

3.4 Testing results

Table 6 shows test results as compiled by FrontierSI, which are representative of the testing carried out in the 10 sectors in the Demonstrator Trial.

Test results are shown for signals as tested by the Demonstrator Project(s) in the sector. As many as three signals (L1, DFMC and PPP) were tested, but in some instances only one signal was tested.

Table 6 – Representative sector test results from Demonstrator Project testing

Sector	Signal	Expected performance (m)		Equipment used	Testing environment
		horizontal	vertical		
Agriculture	SBAS L1	0.5	1.1	Professional	Open sky to lightly obstructed
	SBAS DFMC	0.6	1.3		
	PPP	0.2	0.5		
Aviation	SBAS L1	0.7	1.3	Professional	Open sky
	SBAS DFMC	0.6	1.1		
	PPP	-	-	n/a	n/a
Construction	SBAS L1	1.1	2.2	Mid-range	Partially to moderately obstructed
	SBAS DFMC	1.8	2.3		
	PPP	0.7	1.2		
Consumer	SBAS L1	2.1	4.0	Consumer	Lightly obstructed
	SBAS DFMC	3.0	5.8		
	PPP	-	-	n/a	n/a
Maritime	SBAS L1	0.9	1.9	Professional	Open sky
	SBAS DFMC	1.4	3.8		
	PPP	0.1	0.2		
Rail	SBAS L1	0.6	0.6	Professional	Partially to significantly obstructed
	SBAS DFMC	1.3	3.4		

Sector	Signal	Expected performance (m)		Equipment used	Testing environment
		horizontal	vertical		
	PPP	0.3	0.6		
Resources	SBAS L1	0.9	2.7	Mid-range and professional	Lightly to partially obstructed
	SBAS DFMC	0.6	2.0		
	PPP	0.2	0.7		
Road	SBAS L1	1.1	3.0	Mid-range	Lightly to significantly obstructed
	SBAS DFMC	2.0	3.1		
	PPP	0.6	1.0		
Spatial	SBAS L1	0.9	1.4	Mid-range	Open sky
	SBAS DFMC	1.0	1.5		
	PPP	0.1	0.2		
Water utilities	SBAS L1	-	-	n/a	n/a
	SBAS DFMC	-	-		
	PPP	0.4	0.8	Mid-range	Open sky to moderately obstructed

As many different applications were tested across a large geographic region in various environments, with different hardware combinations, it is not surprising to see the results varied per sector. Generally, the test results described above match the expected performance.

4. Analytical approach

In its most basic form, the analytical approach for the assessment of economic benefits focussed on quantifying the benefits anticipated by individual Demonstrator Projects, scaling each benefit up to represent the entire sector (and apportioned to Australia and New Zealand geographies) before summing all benefits to identify a final estimate. The purpose of this section is to provide further insight into EY's approach and elaborate on the steps taken to arrive at the final output.

This assessment is fundamentally based on the 27 Demonstrator Projects that participated in the Demonstrator Trial. Therefore, while the findings of this analysis represent anticipated economic benefits to each sector, this assessment does not constitute the full quantum of benefits that could be expected to accrue. This quantum would likely be considerably larger once all potential benefits are considered.

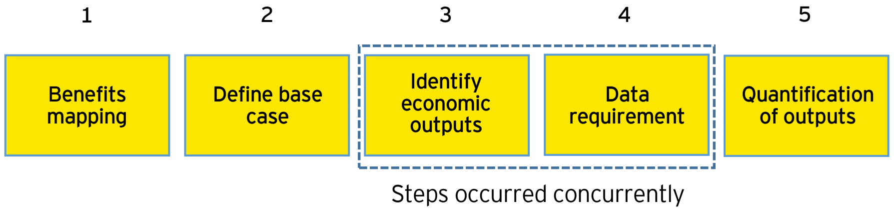
Because this analysis was also based on the benefits identified by each Demonstrator Project, there might also appear to be a bias (at a project, sector, or geography level) for or against certain signal types that may not play out in reality.

This analysis does, however, provide guidance on the anticipated baseline benefits that could accrue owing to an operational SBAS.

The approach utilised for the purposes of the Demonstrator Trial was a five-stage assessment methodology as outlined in Figure 9. This same five-stage process was applied to each Demonstrator Project and was discussed with and endorsed by Demonstrator Project participants.

Nevertheless, it is important to note that there was a diverse range of Demonstrator Projects, which presented challenges when working through the economic benefit modelling. In other words, the specifics of each project inevitably impacted on the level of detail that was undertaken across each of these five stages.

Figure 9 - Five-stage assessment methodology



4.1 Benefits mapping

As with all economic benefit assessments, the most important issues to understand are the categories of benefits and whom they accrue to.

A benefits mapping exercise was undertaken for each Demonstrator Project, which helped answer these questions by mapping out the various benefits anticipated from use of the SBAS signals. Each benefit map comprised the following five components:

- SBAS benefits

  The general benefits of an operational SBAS that can be envisioned regardless of sector or Demonstrator Project. In a practical sense, these are the broad categories that might be used to justify investment in an operational SBAS through a business case and reflect the benefits discussed in Chapter 2.

- SBAS sector benefits

  The benefits of the SBAS signals that generally accrue to the sector in question.

- Operational impacts

  The specific impacts that can be foreseen for each Demonstrator Project. Many of these may also be relevant across the sector.

- **Operational benefits**

  The specific benefits that Demonstrator Projects will cite when they look to justify investment in the technology, i.e. how operational impacts translate into firm/sector benefits.

- **Economic benefits**

  The quantification of operational benefits across sectors as they impact on the economy, i.e. how the operational benefits flow through into the economy.

4.2 Define base case

To ascertain the additional benefits that accrue from the SBAS signals, it was important to understand the status quo – essentially what would happen in the absence of the SBAS signals. This allowed for comparison of the additional benefits to the status quo. Developing a base case required an understanding of two elements.

4.2.1 An understanding of the existing operating model

Understanding how a Demonstrator Project operates within a sector and the positioning technology that is currently employed was important to determine how the SBAS signals would likely affect the status quo.

Many Demonstrator Projects already used existing positioning technology and so the focus was on understanding the additional improvements an operational SBAS could provide. However, in some instances, positioning technology is not widely used and so the transformational benefits of the SBAS signals could be assessed.

4.2.2 An estimation of the future without the SBAS signals

The base case was not simply based on the present, it also needed to consider how the future might evolve in the absence of the SBAS signals. This involved two components:

- Forecasting business as usual growth or the status quo
- Understanding other technological change.

In forecasting growth, publicly provided forecasts were used wherever possible. Where this was not possible, past data and trends were used to justify future expectations. In the absence of data, transparent and informed assumptions were made, based on consultation with the sector and subject to approval from FrontierSI and relevant Demonstrator Projects. In many cases growth rates were not employed to maintain a level of conservatism, as speculation about future growth rates in the absence of formal studies is inherently risky.

It was also necessary to understand how technological change in the absence of the SBAS signals may have affected the sector. For example, self-driving vehicles may use alternative private technologies, or avoid enhanced GNSS positioning entirely in favour of Light Detection and Ranging (LiDAR)/radar systems and vehicle-to-vehicle communication systems augmented by locally transmitted reference points.

The future uptake path also had to be accounted for. Adopting a new technology or standard is often the most risky and expensive part of a new technological venture. Therefore, this uptake path was subject to significant uncertainty. This uncertainty was mitigated through discussions with Demonstrator Projects, research, and production of transparent assumptions.

Feedback was sought from Demonstrator Projects to define each base case. Where any challenges existed and validation was required, FrontierSI assisted to identify appropriate parties to undertake this.

4.3 Identification of economic outputs and data requirements

Once a benefit map was developed showing how the SBAS signals drove individual firm, sector, and economy-wide benefits, and a base case was agreed (i.e. there was a baseline to compare benefits to), anticipated economic benefits and associated evidence bases were confirmed. These benefits therefore represented a demonstrable improvement on the status quo.

EY took a pragmatic approach to benefit quantification and focussed on those economic benefits which comprised most of the quantifiable economic benefits within the respective sector, or those areas where data was sufficient to make an informed estimate.

Practically speaking, this involved discussion of the data and methodology required to quantify each economic benefit. For example, in the agriculture sector, it is anticipated that PPP will enable the use of precision spraying by farmers who previously did not have access due to cost barriers. Precision spraying is anticipated to reduce the degree of overlap when spraying herbicides, pesticides, and fertiliser, and reduce operating expenditure associated with use of the sprayer given it will cover the same area with less distance travelled.

To support this calculation, data similar to the following was requested:

- Average cost of fertilisers, herbicides, and pesticides deployed per hectare
- Average operating expenditure of sprayer per hectare
- Number of hectares currently subject to overlaps
- Anticipated reduction in hectares subject to overlaps due to precision spraying.

In addition, one of the unique issues in this study was the presence of three test signals which provided users with different levels of performance regarding accuracy and integrity and hence had the potential to generate different economic benefits.

Where the type of signal being tested was material to the outcome, the incremental benefits of different signal types have been reported. This should help inform decision making around future government investment.

Where practically feasible, effort has been made to report economic benefits for Australia and New Zealand separately to show how each country would benefit from an operational SBAS.

4.3.1 Quantitative and qualitative assessments

EY has endeavoured to present quantifiable economic benefits throughout this analysis wherever possible. Quantitative analysis tends to be less subject to bias and can be directly used to understand whether benefits outweigh costs when making an investment decision.

However, in some instances, a lack of data, or certainty around the finer details of a benefit required scaled back quantitative assessments or a stronger focus on qualitative assessments.

A qualitative analysis differs from a quantitative analysis in that benefits are described based on research or workshop outputs, rather than assigned a monetary value.

Qualitative analysis can still be robust, particularly where the scale and magnitude of potential benefits can be informed by other studies or experiences with similar technologies. This quantification approach has not been used as an input into quantitative modelling, but to provide support to quantitative estimates.

Three distinct economic assessment approaches to qualitative assessment have been utilised throughout this Demonstrator Trial:

Qualitative (scale and magnitude)

In several instances, quantitative information has been relied upon to provide an indication of the likely scale and magnitude of potential benefits. However, because of uncertainty in the data or a lack of confidence in issues such as scaling, the analysis has not been carried through into the aggregate modelling.

Qualitative (case study)

Case studies are also a useful way of expressing potential benefits where the precise monetary value is not known with confidence. The use of case studies provides an indication of the potential size of benefits so that decision makers understand whether a benefit is material, or not. This approach has not been used as an input into any quantitative modelling, however it is included in this Economic Benefits Report.

Qualitative (description)

In some instances, it was not possible to undertake a case study. Accordingly, a qualitative description of the anticipated benefits has been undertaken.

4.4 Quantification of outputs

The final phase of the assessment was to take the information gathered through stages one to four and put it into a format that enabled the production of outputs for utilisation in this Economic Benefits Report.

The microeconomic modelling revealed a range of core components, and limitations that require definition and discussion.

4.4.1 Timeframe for analysis

For any economic modelling, a timeframe for analysis, which includes both a start and an end date, must be confirmed. Timeframes for assessment are naturally subjective and have a range of pros and cons depending on which timeframe is employed. In general, shorter timeframes provide greater levels of confidence in inputs, but undersell potential benefits. Longer timeframes, when accompanied with relevant discount rates, tend to present a more accurate representation of benefits, but with levels of confidence decreasing the further the timeframe is extended.

For this assessment, a start date of 2020 and an end date of 2050 has been utilised, thereby enabling the potential economic benefits of the SBAS signals to be measured over a 30-year period. The 30-year time horizon has been chosen for the following reasons:

- The start date aligns with the expected date that the technology will be put in place and adopted, with the DFMC operations standard anticipated in 2020.
- The end date aligns with two typical design lifetimes for geostationary satellites, which average approximately 15 years. This allows for the benefits to offset the capital cost of renewal.

It is worth noting, however, that the results of some Demonstrator Projects suggested the benefits might start to accrue later than 2020 depending on the assumptions made about uptake rates.

4.4.2 Benefit attribution

Benefits identified as part of this analysis have taken on one of two forms. They either represent an augmentation of existing operational processes, or they represent the enablement of new operational processes.

With regards to the former, the SBAS signals were viewed as being the sole source of the improvement over and above the status quo and as such accrued 100 percent of the anticipated benefits.

In terms of the latter, the SBAS signals were viewed as one of many enablers for a new operational process which provided benefits over and above the status quo. This presented itself in two ways: positioning attribution and SBAS attribution.

Positioning attribution

Acknowledges that there are other necessary components for the enablement of new technologies and processes. For example, positioning technologies form one of many components for the development of CAVs.

SBAS attribution

Acknowledges that the SBAS signals are not the sole positioning option on offer and would likely have a portion of the market as opposed to all of it. For example, this would mean that the SBAS signals are not the sole method for achieving the positioning component of CAVs, as there could be additional methods such as RTK and differential GNSS (DGNSS).

The purpose of attribution is to acknowledge that there are other components or positioning technologies that may make a given benefit come to fruition and as such must be reflected in the corresponding benefits analysis.

4.4.3 SBAS signal attribution

A further level of SBAS signal attribution was also undertaken (i.e. between L1, DFMC and PPP). In determining signal attribution, EY worked closely with FrontierSI to understand the expected performance of each signal, before comparing it to the positioning requirements of each benefit to gauge an attribution factor.

In practical terms, the default position with regard to signal attribution is for all three signals to accrue benefits. L1 and DFMC are assumed for modelling purposes to provide a similar level of positioning performance and therefore share the same attribution rates throughout this analysis. Further, where PPP is assumed to oscillate between a minimum accuracy performance level of one metre and maximum level of decimetres, it accrues the same benefits as L1 and DFMC, in addition to incremental benefits derived from decimetre level accuracy.

Based on this logic, PPP is generally expected to accrue 100 percent of the benefits when deployed, with a slight discount factor applied to L1 and DFMC to reflect its limitation to sub-metre benefits only. This discount factor varies only when EY has had a good understanding of the marginal benefit per unit of increased accuracy, which has so far only occurred in the agriculture sector.

PPP does not accrue benefits in three specific and significant scenarios:

- Where a benefit requires safety of life (SoL) integrity, which PPP does not provide and L1 or DFMC does
- Where the sector is unlikely to adopt PPP due to the greater associated receiver costs
- Where a benefit requires fast convergence to decimetre accuracy, or where constant convergence at decimetre accuracy levels is required.

The positioning needs of anticipated benefits identified throughout this Demonstrator Trial were either presented as a minimum threshold, such as regulatory requirements, or sliding scales whereby benefits increased as accuracy increased. Benefits then accrued to all signals in instances when accuracy thresholds sat at the sub-metre level, for example in C-ITS applications in the road sector.

In instances where accuracy thresholds sat at the decimetre level, benefits solely accrued to the PPP signal, such as greater cargo carrying capacity due to enhanced SBAS-enabled under keel clearance. Where accuracy requirements followed a sliding scale rule, benefits were again attributable across all signals in a manner reflecting the exponential growth of benefits as accuracy shifted from sub-metre to decimetre levels. An example of this is precision spraying in the agriculture sector.

These signal attributions were ultimately based on a survey of user requirements or an informed assumption was made through discussions with Demonstrator Project(s).

4.4.4 Scaling

In most instances, economic benefits identified at a Demonstrator Project level could be scaled up to a sector benefit and/or scaled across geographies.

However, there were many instances where this was not possible due to data limitations. For example, several of the economic benefits in the maritime sector were ring-fenced to a single port or harbour environment. Each harbour environment has very unique characteristics which mean that scaling would need to be undertaken on a port-by-port basis. This was not possible given the scope of the engagement.

In this sense, the results presented in this report represent a level of inherent conservatism.

4.4.5 Confidentiality

Regardless of whether economic benefits have been qualitatively or quantitatively expressed, there was a need for clear documentation of methodologies and data requirements. Specific data requests have been retained and relied upon for all projects, but have not always been presented in this report for confidentiality reasons.

4.4.6 Discount rates

Discount rates are used in finance, economics, and policy-making to determine the present value of an investment, when the costs and benefits are spread over a longer time horizon. At a practical level, the higher the discount rate, the lower the value that is placed on benefits that accrue in the future, and vice-versa.

A nominal discount rate does not take inflation into account, whereas a real discount rate does. EY has utilised a 6.5 percent real discount rate as the default rate for its modelling purposes, which is an average of the seven percent real discount rate outlined by Infrastructure Australia[9] and the six percent real discount rate outlined by Treasury New Zealand[10].

In acknowledgement of the fact that different readers will hold different views about the likelihood of economic benefits coming to fruition, EY has undertaken a sensitivity analysis to provide a range for debate. As outlined in Table 7, the discount rate has been used as a proxy for this sensitivity and a lower and upper bound of 4.5 percent and 8.5 percent respectively has been deployed.

Table 7 – Discount rates and sensitivity analysis

Confidence level	Discount rate
Low	8.5%
Default	6.5%
High	4.5%

4.4.7 Economic model employed

A microeconomic model for each Demonstrator Project (and sector) has been developed. The aggregation of the outputs from each of these economic

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[9] Infrastructure Australia (2018) Assessment framework: for initiatives and projects to be included in the Infrastructure Priority List. Retrieved from: http://infrastructureaustralia.gov.au/policy-publications/publications/files/IFA_Infrastructure_Australia_Assessment_Framework_Refresh_v26_lowres.pdf

[10] The Treasury (2018) Discount rates. Retrieved from: https://treasury.govt.nz/information-and-services/state-sector-leadership/guidance/financial-reporting-policies-and-guidance/discount-rates

models has informed the summary of benefits in this Economic Benefits Report.

A microeconomic modelling approach was preferred as it provides a point of difference from previous studies as well as better reflects the detailed operational testing undertaken through the Demonstrator Trials.

4.4.8 Economic modelling limitations

Economic modelling is a simplification of reality. Economies are complex and are subject to an incalculable number of interactions between rational and irrational economic actors. By attempting to model these interactions, it is necessary to make assumptions about core inputs. A sample of these include current behaviours, future expectations, the number of parties present in an economy, the prices of operational inputs, and output prices.

The translation between what occurs in the real world and what is modelled as part of an economic model is clearly subject to debate.

It is acknowledged that the modelling undertaken in this Economic Benefits Report will not perfectly mirror what occurs in reality. However, significant efforts have been undertaken to try to arrive at reasonable assumptions to frame what scale and magnitude of economic benefits could accrue, by sector, by signal and by geography attributable to an operational SBAS.

More specific limitations of each sector economic model are provided after each sector Chapter.

5. Benefit categories

Demonstrator Projects reported a wide variety of economic benefits that they expect to accrue to their operations, and the wider sector of which they are a part, should the SBAS signals meet necessary performance criteria. In general, these benefits will help businesses generate new revenue, save money or generate wider public benefits (including reduced health and safety impacts).

The anticipated range of economic benefits from Demonstrator Projects is diverse, from transformative benefits to entire sectors through to minor operational savings for individual firms. While at face value these economic benefits appear to be specific to their respective sectors, a closer look highlights key themes which emerge across sectors. These themes have formed the basis of the benefit categories detailed below.

5.1 Health and safety

This category captures benefits associated with the improved health, safety, and welfare of people in the workplace. It not only focuses on the reduction of actual fatalities and serious injuries, but also the reduced risk of such incidents occurring through labour time savings (which reduces worker exposure to workplace hazards). Collectively this results in reduced risk of injuries and fatalities which leads to greater health and safety outcomes and an improved quality of life.

There are several ways in which the SBAS signals can contribute to enhanced health, safety, and quality of life improvements.

- The SBAS signals can help to complete potentially hazardous tasks with greater accuracy, leaving less room for error. An example of this would be in the aviation sector where accurate vertical positioning reduces the risk of Controlled Flight into Terrain (CFIT) accidents.
- The SBAS signals can help automate tasks that were previously labour intensive and dangerous, thereby reducing the likelihood of injury, but also reducing the number of people who must undertake these hazardous tasks. For example, the enablement of automated C-ITS safety applications such as forward collision warnings, intersection movement assistance, and control loss warnings, where vehicles can autonomously take over a vehicle to reduce the risk of road crashes.
- The SBAS signals can improve quality of life by enabling greater autonomy for those with visual and intellectual impairment. This is particularly relevant in the case of navigational assistance for visually impaired people. The high positioning resolution afforded by the SBAS signals enables the potential for haptic sensory systems which can assist users to navigate urban environments without the need for a guide dog.

Quantification of these outcomes involves placing a monetary value on the improvement of quality of life, and on lives saved, coupled with any reduction in probability of incidents occurring. In general, a blended Statistical Value of Life metric, derived from multiple sources, has been used to understand the health and safety benefits. In isolated instances, disability adjusted life year calculations have also been undertaken.

5.2 Operating expenditure savings

Within this category there are two main benefits areas.

5.2.1 Labour productivity

Labour costs are typically among the most significant expense items for firms. Reducing labour input costs, if output remains the same or improves, can have positive effects for individual firms, sectors, and the economy.

Some uses of the SBAS signals will allow firms to produce the same amount of output with fewer labour inputs or will be able to produce more output with the same level of inputs. Economists think about this in terms of labour productivity and the SBAS signals could enhance labour productivity across several sectors. Benefits within this category have accrued through two predominant operational changes:

- **Technological innovation and automation**

  There is a range of tasks that can be automated through the presence of the SBAS signals so that labour is not required to achieve the same level of output. This can be considered a direct reduction in labour costs. An example of this would be better identification of rail defects, whereby rail maintenance workers spend less time finding defects before commencing maintenance tasks.

- **Reduced risk**

  There are certain instances where sub-optimal (but rational) operating practices are being employed because there are risks to health and safety. These practices can be rectified through a greater understanding of risk and adoption of risk-reducing technologies. An example of this would be haul trucks within mines operating at sub-optimal speeds (from an economic standpoint) due to a lack of confidence in collision avoidance systems (CAS).

Firms then face several operational decisions to use the value that is created from an operational SBAS. This Economic Benefits Report has focused on the value that is saved rather than the specific operational decision.

- **The economic benefit will predominantly be considered as a cost saving**

  For example, if an individual firm budgets for three workers at $30,000 each per year to complete 5,000 units of production and discovers that it only takes two workers to complete that amount of work, the direct labour savings are $30,000 per year.

- **The automation of certain tasks that have traditionally been labour intensive can allow for greater returns to labour**

  In some cases, benefits can provide for a realignment of the labour market, providing opportunities for existing employees to focus on higher value-added activities. These shifts can result in economy-wide productivity gains.

Across these dimensions, it is important to think about the dynamic impact of these operational changes. Wages may still increase, particularly where workers require specialised training to operate, calibrate, and interpret data from an operational SBAS. However, returns to technological change (multifactor productivity) are uncertain, and in some cases the benefits may accrue more strongly to the owners of the technology (capital) rather than the technology itself.

The microeconomic modelling has made assumptions on a case-by-case basis about the way in which firms may react when faced with labour productivity decisions, rather than generating endogenous firm decision-making calculations. This level of simplification is considered appropriate given that the purpose of this assessment is to provide decision makers with a sense of scale and magnitude of economic benefits possible.

5.2.2 Other productivity

Operational expenses are those expenditures that a firm incurs to engage in any activities not directly associated with the production of goods and services. These operating expenses include a variety of factors broadly relating to compensation, office and administration, sales and marketing and cost of goods sold. Of most relevance to this report is the last factor, which includes expenses such as:

- Freight in and freight out
- Direct materials
- Rent of production facilities
- Compensation for production personnel
- Repair of production equipment and facilities
- Utility costs for production facilities, specifically fuel costs

Discussions with Demonstrator Projects suggest a range of operational efficiencies may be enabled through the deployment of the SBAS signals. These efficiencies include fuel savings (for example because of fewer flight diversions), a reduction in surveying equipment required to undertake the same job (such as those required for mapping purposes), and reduced maintenance costs (for example as a result of more timely servicing of mining fleet vehicles). Benefits resulting in savings across any of these line items will be counted as operating expenditure savings.

Similar to the labour productivity category, the microeconomic modelling undertaken for this analysis has not been able to endogenously distil complex decisions about how a firm chooses to ‘bank’ these savings – for example does it produce more output or does it take the operating savings in the form of higher profits? Assumptions on a case-by-case basis have therefore been made about the way in which firms may react when faced with labour productivity decisions.

5.3 Environmental

Environmental benefits are associated with activities which reduce the adverse effects of the production and operation of goods and services on the environment. These adverse effects include both the degradation of the natural and physical environment and greenhouse gas emissions.

Discussions with Demonstrator Projects suggest the scope of environmental benefits as a result of the SBAS signals could accrue in areas of: reduced emissions from reduced fuel consumption; reduced harmful runoff from more effective and efficient chemical applications on farms; and reduced collateral damage from more accurate drilling operations in the asset management and resources sector.

Where possible, EY has endeavoured to capture such benefits quantitatively, or at the very least qualitatively where data is not available or robust.

5.4 Capital expenditure avoided

Capital expenditure is considered to be those funds deployed by the private and public sector to buy durable goods, in a particular property, industrial buildings, equipment, and infrastructure.

Avoided capital expenditure comes in the form of either deferred capital investment, for example, delaying road upgrades due to reduced wear and tear, or direct avoidance, such as no longer requiring future facilities or divestment of existing facilities and associated operating expenditure.

The SBAS signals offer potential benefits across both fronts. For example, L1 and DFMC are anticipated to reduce the need to invest in Instrument Landing Systems (ILS) in the aviation sector. A reduced need for terrestrial signal systems across rail networks is also anticipated due to L1 and/or DFMC-enabled track management systems, and in certain instances, a reduced need for temporary base stations used as part of RTK positioning systems.

5.5 New revenue

In addition to economic benefits that have impacts on existing activities (such as reduction in operating expenditure, improved productivity, or reductions in health and safety risks), the SBAS signals are also expected to enable new applications and technological innovations to be taken to market. Equally, the SBAS signals can enable new revenue streams to come to fruition from existing activities.

Quantitative analysis has not focussed on the likelihood of growing new markets as this has not come through discussions with Demonstrator Projects to date. This might in part be definitional – it is difficult to predict the impact of new markets and revenue streams that have not materialised – but also may be due to commercial sensitivities.

It is also important to note that this assessment has not looked to quantify the potential to develop a new sector enabled by the SBAS signals – although this remains a distinct possibility and warrants further investigation through separate analysis.

6. SBAS benefits

This Chapter provides a summary analysis around the quantitative and qualitative benefits anticipated from the SBAS signals across the economy, as informed by the Demonstrator Trial. At a high level, benefits have been presented across the following dimensions:

By sector

To understand how SBAS signal benefits are distributed across the various sectors, both in totality and by geography.

By benefit category

To understand how the SBAS signals benefit the economy. For example, are they expected to generate significant labour savings? Or unlock major new markets? Or are they anticipated to result in significant environmental benefits?

By geography

To understand where the SBAS signal benefits accrue. For example, do benefits accrue solely in Australia? Is the benefit distribution proportionally consistent with the relative economic sizes of Australia and New Zealand?

By signal type

To understand which of the SBAS signals contributes the most to anticipated benefits. This will help inform decision makers should investment in an operational SBAS be pursued by the Australian and New Zealand governments.

It is important to note that quantified benefits are limited to those identified by Demonstrator Projects. It is acknowledged that there remain benefits known to EY which have not been included as part of this analysis and benefits not known to EY which may drive significant benefits to the economy in the near or long-term future. To that end, the final figures included in this report are likely to be conservative.

A range of additional applications raised through this analysis is provided in Chapter 18.

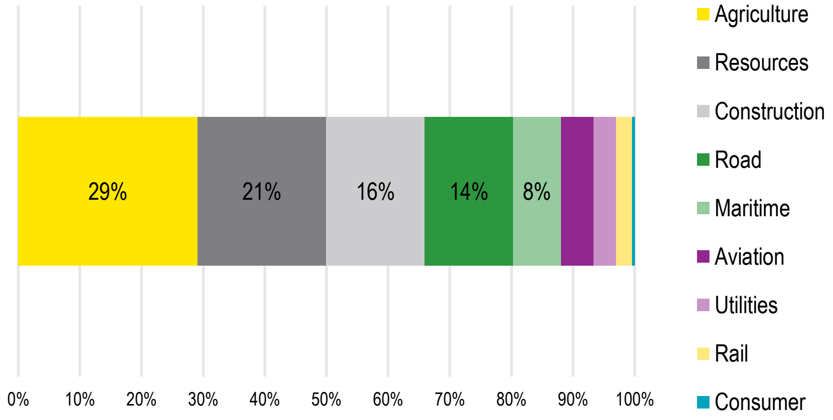
The purpose of this Chapter is therefore to convey the cumulative quantitative benefits anticipated by the SBAS signals across the Australian and New Zealand economies. It represents the summation of all quantified benefits over the 30-year assessment period in PV terms, from all 27 Demonstrator Projects that had sufficient data and represents nine of the ten sectors included in the trial.

6.1 Benefits by sector

Total benefits of **PV AUD $7.6b** are anticipated across the Australia and New Zealand economies from the deployment of the SBAS signals – L1, DFMC, and PPP – over a 30-year period. A sensitivity analysis reflects a lower bound and upper bound figure of between PV $5.6b and PV $10.8b.

Agriculture (29 percent), resources (21 percent), construction (16 percent), and road (14 percent) stand to benefit most from deployment of an operational SBAS, as shown by Figure 10.

Figure 10 – Economic benefits by sector



This Economic Benefits Report demonstrates that all sectors expect to see tangible benefits from the deployment of the SBAS signals and in certain instances these benefits are quite large. More importantly, however, this analysis has shown that benefits are not limited to the aforementioned sectors, and accrue, to varying degrees, across all sectors. Table 8 provides a summary of benefits by sector.

Table 8 – Quantum of benefits across sectors (30-year, AUD)

Sector	Benefits
Agriculture	$2.2b
Aviation	$404m
Construction	$1.2b
Consumer	$34m
Maritime	$590m
Rail	$190m
Resources	$1.6b
Road	$1.1b
Spatial	N/A
Water utilities	$280m
Total	**$7.6b**

Note: Totals may not sum due to rounding

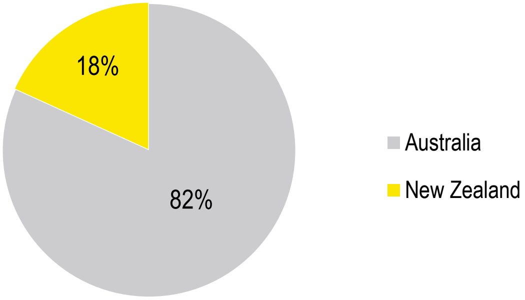
This broad benefit coverage suggests an operational SBAS has potential as a public good offering from government. A public good is defined as a commodity or service that is provided without profit to all members of a society, either by government or by a private individual or organisation. It requires the commodity to be non-rivalrous, which is defined as a service that does not reduce in availability as people consume it, and non-excludable, which is defined as a good which can be accessed by all.

Given that the SBAS signals do not reduce in availability as people consume them, and there is an inability to encrypt the L1 and DFMC signals, this reinforces the notion that the system may be provided as a public good offering.

6.2 Benefits by geography

As depicted in Figure 11, approximately 82 percent of benefits are anticipated to accrue to Australia, and 18 percent to New Zealand, representing a ratio of roughly 4:1 in benefits accrued. This represents benefits of **PV AUD $6.2b** to Australia and **PV AUD $1.4b** to New Zealand over the 30-year assessment period.

Figure 11 - Economic benefits by geography



The spread of economic benefits across Australia and New Zealand shows that the benefits of the SBAS signals are material to both geographies, and that they are not unduly disproportional to one country over another on a per population basis (New Zealand has roughly 15 percent of the Australian population). The key implications of this are that the benefits identified through this study support the potential for investigation of a regional service or a shared approach to delivery.

The distribution of benefits across sectors differs between the two geographies. As shown in Figure 12, resource (25 percent), agriculture (23 percent), construction (17 percent), and road (15 percent) stand to gain the most within the Australian economy. As shown in Figure 13, agriculture (57 percent) is the overwhelming beneficiary of an operational SBAS in New Zealand, followed by road (13 percent), construction (12 percent), and aviation (nine percent).

Figure 12 – Australian benefits by sector

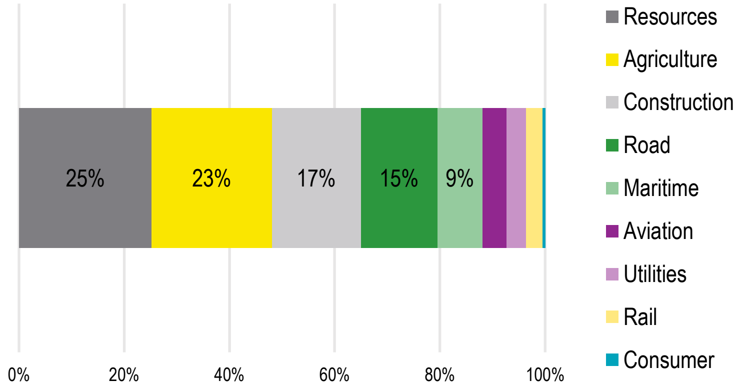
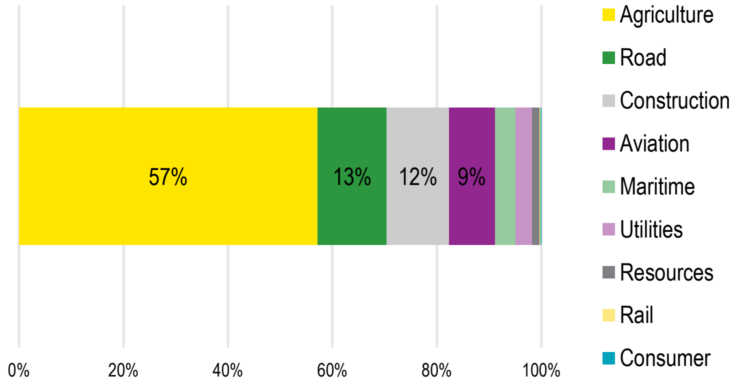


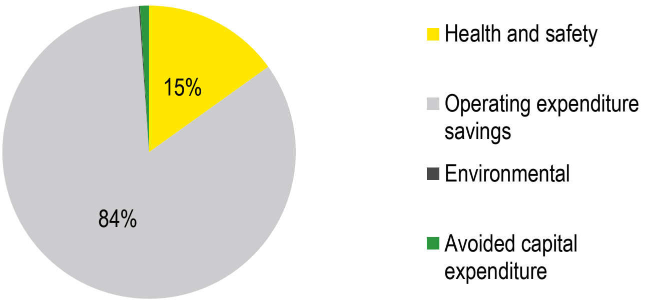
Figure 13 – New Zealand benefits by sector



6.3 Benefits by benefit category

As outlined in Figure 14, operating expenditure savings (84 percent) and health and safety (15 percent) have the greatest representation across the benefit categories, which is reflective of the main themes coming through discussions with Demonstrator Projects and the wider sectors covered in this analysis.

Figure 14 - Economic benefits by benefit category



There are two additional observations from this analysis that are important to clarify.

There is overlap between operating expenditure savings and environmental benefits

It is critical to note that the above benefit segmentation (by benefit category) inherently conflates benefits. This is most obvious example of this is when considering the relationship between operating expenditure savings and environmental savings.

For example, in a scenario where reduced fuel consumption is possible through the SBAS signals, this has been captured as a reduced operating expenditure benefit as it is the direct result of the benefit. However, it is also expected that this reduction in fuel consumption would result in reduced greenhouse gas emissions.

In this sense, it is slightly misleading to solely attribute all the quantifiable economic benefits to operational savings alone. Rather, it is expected that there will be many flow-on implications (particularly for environmental and possible reduced health and safety) that are likely to be significantly under-represented in this analysis.

A decision has been made to directly attribute benefits (i.e. to operating expenditure savings to individual firms and sectors) rather than to wider externality benefits to society. This decision was made on practical grounds given the difficulty in collecting data on some wider externality benefits and then removing any double counting

Environmental benefits, health and safety benefits and avoided capital expenditure benefits are all under-represented quantitatively

While the perceived quantifiable benefits of these three categories is low (16 percent of total benefits) these categories are more strongly represented once qualitative benefits are contemplated.

Chapter 19 demonstrates that while operating expenditure savings is still the dominant benefits category (73 percent), the total count of these three other categories is 27 percent. Specifically, under a simple benefit count: health and safety (20 percent), environment (four percent), and avoided capital expenditure (three percent).

6.4 Benefits by signal

Understanding benefits as they accrue to each of the three signals being trialled provides decision makers with an understanding of the implications of their choice when it comes to making investments in the SBAS signals.

L1 and DFMC are assumed to accrue **PV AUD $5.58b** in economic benefits, and PPP accrues **PV AUD $5.28b** in benefits over a 30-year period. This reflects the proportion of total benefits attributable to each of the SBAS signals, noting there are overlaps where benefits are attributable to all three signals. As noted earlier, L1 and DFMC are assumed for modelling purposes to provide a similar level of positioning performance and therefore share the same attribution rates throughout this analysis.

On the face of it, these results imply that there are not major differences between the signals in practice. This is not the case. Figure 15 shows that there is likely to be significant sectoral differences in terms of signal uptake.

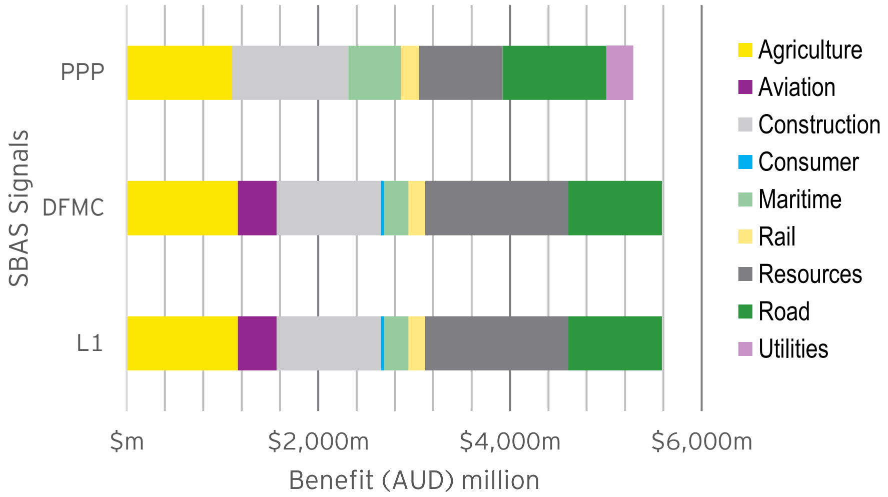
L1 and DFMC are anticipated to play a comparably stronger role in the resources sector than PPP and are anticipated to be the sole SBAS signals relevant for the aviation sector.

PPP, however, is anticipated to play a comparably stronger role in the construction sector, the maritime sector, rail sector and water utilities sector.

It is important to note that there are significant overlaps between the signals when calculating the economic benefits. This is the reason that the bars in Figure 15 do not sum to the $7.6b total. The signal attribution methodology is described in more detail in Chapter 4.4.3.

Chapter 19 further demonstrates the anticipated economic benefits by signal type.

Figure 15 – Economic benefits by signal type, by sector (30-year, AUD)



6.5 Sensitivity testing

As noted throughout this report, a range of assumptions have been made to develop reasonable models of the potential economic benefits of the SBAS signals across multiple sectors. These assumptions were established through rigorous desktop research and significant consultation with sectors and experts to ensure they were reflective of each Demonstrator Project.

Sensitivity testing is important as it can provide a sense of the potential breadth of economic benefit associated with the SBAS signals under different input assumptions. Sensitivity testing can also allow for a more meaningful way of facilitating comparisons with existing and future analyses of the economic benefits that will accrue due to uptake of the SBAS signals.

For this report, three major sensitivities of the following were initially considered:

- Uptake scenarios
- Benefit-by-benefit methodology
- Discount rates

Fundamentally, the micro-economic modelling was based on a unique uptake rate for each economic benefit. Choosing an uptake rate sensitivity for each economic benefit is challenging and unproductive given the wide range of potential alternatives (i.e. changing curve type, maximum uptake rate, inception point, etc) and the lack of consensus about what should be tested.

Similarly, agreeing which part of the calculation methodology to sensitivity test for a given economic benefit was considered challenging and unproductive given the wide range of potential alternatives (methodology, input variables, extent to which these could change).

The following discount rates have been applied across each sector result as demonstrated in Table 9.

- 8.5 percent (assumes a lower level of confidence in the findings)
- 6.5 percent (discount rate used in modelling)
- 4.5 percent (assumes a higher level of confidence in the findings).

Table 9 – Sensitivity testing, by sector (30-year, AUD)

Sector	Discount rate sensitivities		
	4.50%	6.50%	8.50%
Agriculture	$3,193m	$2,206m	$1,567m
Aviation	$485m	$404m	$313m
Construction	$1,718m	$1,213m	$879m
Consumer	$49m	$34m	$24m
Maritime	$755m	$588m	$470m
Rail	$281m	$193m	$135m
Resources	$2,295m	$1,581m	$1,115m
Road	$1,600m	$1,084m	$753m
Water utilities	$398m	$277m	$197m
Total	**$10,773m**	**$7,581m**	**$5,454m**

6.6 Wider consequences of an operational SBAS

This investigation has focused on the economic benefits that can potentially accrue to the Australian and New Zealand economies from the introduction of an operational SBAS. The benefits presented in this report all manifest as positive implications for individuals, firms, sectors, and economies. However, it is noted that economies are ecosystems and that any change in formation of capital and labour will result in implications elsewhere in the economy.

In light of this, it is noted that there could be a range of wider considerations from an investment in an operational SBAS that are worth acknowledging; including the effects of an SBAS service on labour productivity, capital investment and competition.

6.6.1 Firms and individuals

An expectation of an operational SBAS is that a range of current tasks performed by humans can be simplified, improved or even replaced with newer and potentially automated processes. Examples of these include reduced time locating defects on rail tracks through enhanced geo-referencing and reduced time inspecting construction work at heights using Unmanned Aerial Vehicles (UAVs).

While these benefits can be presented quantitatively in an economic study, it is not possible to present all the effects that may occur in practice as firms (and economies) all have unique pressures and objectives.

In general, it would be expected that any labour freed up because of the implementation of an operational SBAS would sit on a spectrum between being available to perform higher-value tasks to being deemed surplus to requirements. Additionally, this time could be ‘banked’ as free time for employees to reduce workloads.

It is also noted that an operational SBAS might have implications for sunk investments in capital equipment. From a pure economic standpoint, it is preferable to utilise capital equipment until the end of its usable life; this maximises its value and should ensure an appropriate return on investment. However, an operational SBAS may accelerate the uptake of newer capital equipment that can result in sunk capital costs for existing investments. An example of this could be investments in an integrated signal system in the rail sector.

Similar to changes in labour productivity noted above, it is possible that firms who invest in new capital as the result of the implementation of an operational SBAS would face choices about existing capital investments. These choices could sit on a spectrum from continue to use existing capital equipment (albeit inefficiently) through to disposal of such equipment.

In both the capital and labour productivity scenario it is possible that negative side effects for individuals and firms could accrue. However, this phenomenon is not new and is a fundamental part of any industrial revolution – for example imagine the wider consequences on labour and capital formations since the establishment of the internet.

At the macro-level (economy level) it is expected that the implementation of an operational SBAS would raise productivity across the economy which only serves to benefit society as fewer inputs will produce the same level of outputs, or the same level of inputs will produce more outputs.

At the micro-level (i.e. individual and firm level) it is expected that decisions about labour and capital would be made on a case-by-case basis.

In the case of labour productivity, it would be expected that on average, and in the short to medium term, decisions would be made to re-focus staff on higher value tasks as there are significant skills shortages and unemployment is running at near record levels. In the case of capital productivity, it is acknowledged that this is a business choice – and so any decision to retain (or replace) capital will always be in the best interests of the firm.

6.6.2 Industry

In addition to implications for individual and firms within an economy, it is acknowledged that there are a range of industries that may be affected through the implementation of an operational SBAS. The clearest example of this is existing positioning service providers, although other industries might also be affected in time.

In the case of positioning service providers, there are a number of different services that are offered at different levels of accuracy and coverage including DGNSS (sub-metre), PPP (decimetre) and RTK (sub-decimetre). It is immediately acknowledged that an open access operational SBAS cannot produce high accuracy results at the sub-decimetre level. In this sense, an operational SBAS should not compete with the RTK providers.

It is also acknowledged that current providers often have customised commercial relationships with their users. Specific positioning requirements and needs of users (such as servicing and technical support) are accommodated in a way that an operational SBAS cannot fulfil.

However, there may be current subscribers that do not have a need for sub-decimetre positioning and do not require additional customised positioning information and other value-add services. These subscriptions may transfer to an operational SBAS in time. In these instances, this may have an impact on existing commercial providers although it is not expected to fundamentally effect the basis for commercial positioning service providers given their value proposition (accuracy and customisation).

At a macro-level, concerns might also be expressed that the provision of an open access SBAS service might erode the incentive to innovate within the sector. The presence of commercial providers who are incentivised to compete with an operational SBAS and ultimately target new customers with heightened positioning needs mitigates this concern.

Additionally, it can be expected that an open access SBAS might encourage more participants in the economy to utilise positioning technology, and therefore growing the ecosystem for the benefit of all current and future providers (commercial or otherwise) over the long-run.

7. Description of sector chapters

Chapters 8 to 17 of this report is the substantive part of this analysis. These Chapters aim to detail at a sector level, the economic benefits anticipated from the deployment of SBAS signals, the positioning needs of each anticipated benefit, current methods available, and the advantage of the SBAS signals to these existing methods. Each sector Chapter is split into the following sections:

Key findings

This section graphically displays the benefits anticipated by the SBAS signals across New Zealand and Australia. Along with key statistics and figures, it typically contains graphs displaying the:

- Size of benefits by benefit category for the sector overall
- Benefits realised from each sector by country
- Portion attributable to different SBAS signals.

Sector description

Provides a description of what is included in the sector (the activities and sub-sectors), the existing size and importance of the sector to the Australian and New Zealand economies.

Use of positioning technology

This section includes a description of how industries in the sector have traditionally used positioning technology.

Demonstrator Project descriptions

Describes each Demonstrator Project, the project's focus and outlines the signals tested.

Anticipated benefits

Provides concise descriptions of operational benefits anticipated. These were generated from the benefits mapping exercise conducted with Demonstrator Projects within the sector.

Positioning needs and current methods

This section explains the positioning requirements which need to be met for the anticipated benefit to be unlocked, the limitations of current methods in meeting these requirements, and how the SBAS signals will meet these requirements.

Sector benefits

This section comprises most of content of the sector sub-Chapters and covers the signal attribution, uptake, a description of the methodologies underpinning quantitative benefits, and the results of the quantitative and qualitative analysis.

- *Signal attribution*: Establishes the confirmed expected performance of L1, DFMC, and PPP within the sector, which then flows through to attribution across each of the anticipated benefits.
- *Uptake rate*: Establishes the uptake curve deployed for the sector.
- *Quantitative benefits*: This section includes the quantified economic benefits generated from EY's micro-economic economic modelling, along with a brief description of the calculation methodology deployed.
- *Qualitative benefits*: This section includes descriptions of each of the qualitative benefits, supplemented with case studies or research where feasible.

Summary

A summary table is included within each sector Chapter, which concisely displays each anticipated benefit, its corresponding positioning needs, the quantum of benefits should the positioning needs be met, and the signal to which the benefit is attributable.

Assumptions and limitations

This section briefly covers of any assumptions used in carrying out the economic modelling exercise for a particular sector.

Agriculture sector

Key findings

The agriculture sector has historically been of great economic importance in both Australia and New Zealand. The sector includes a broad range of users, from advanced large-scale operations to smaller operations which still primarily rely on manual labour. Demonstrator Trials within the agriculture sector occurred across the following sub-sectors: horticulture, livestock, broadacre, and forestry.

Highlights

Total benefits of present value **(PV) AUD$2.2b** are anticipated in the agriculture sector from the deployment of the SBAS signals over a 30-year period. Of the total benefits, 45 percent (**PV$990m**) accrues to the broadacre sub-sector, 41 percent (**PV$900m**) to the livestock sub-sector, nine percent (**PV$203m**) to the forestry sub-sector, and five percent (**PV$110m**) to the horticulture sub-sector. Geographical splits across the overall sector and each sub-sector are presented in the next page. A selection of benefits consists of:

- Up to $100 in savings per dairy cow, per annum, through enhanced pasture utilisation derived from L1 DFMC enabled virtual fencing. This is anticipated to reduce feed and fertiliser intake resulting in **PV$820m** in total savings over a 30-year period.
- Greater uptake of variable rate technology (VRT) within the broadacre sub-sector through better precision yield mapping availability, resulting in enhanced yields to the value of **PV$520m**.
- Greater penetration of precision spraying within the horticulture and broadacre sub-sectors resulting in a reduction in fertiliser, herbicide, pesticide, and water over-spraying generating **PV$310m** in operating expenditure savings.
- Improved yields from greater penetration of non-RTK controlled traffic farming (CTF) in the broadacre sub-sector is anticipated to amount to **PV$250m** over a 30-year period.
- 2,700 health and safety incidents avoided in the forestry sub-sector from labour time savings derived from enhanced geo-referencing, mapping, and surveying, with a value of **PV$123m** over a 30-year period.
- Six million sellable Australian adult sheep saved over a 30-year period, at a value of **PV$80m**, resulting from enhanced animal tracking enabling early detection of predation events.

Quantifiable benefits

Figure AG1 – Benefits by sub-sector (30-year, AUD)

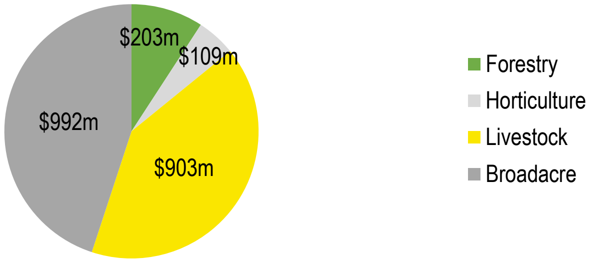


Figure AG2 – Benefits by benefit category (30-year, AUD)

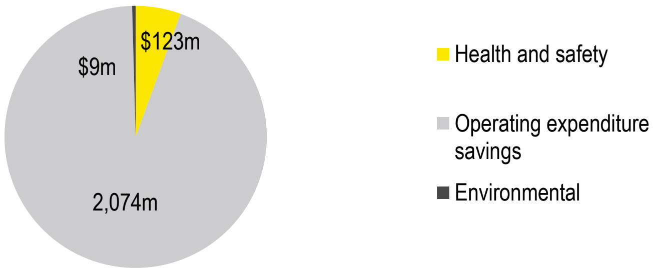


Figure AG3 – Benefits by geography (30-year, AUD)

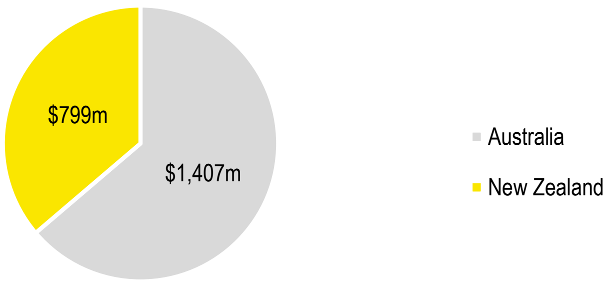


Figure AG4 – Sub-sector benefits by geography (30-year, AUD)

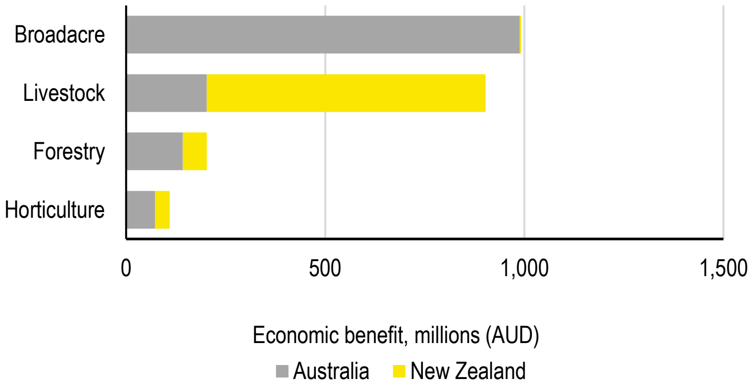
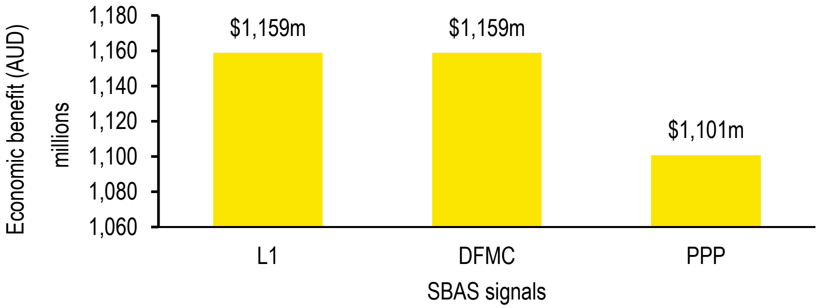


Figure AG5 - Benefit by signal type (30-year, AUD)



8. Agriculture sector

8.1 Sector description

Agriculture is the practice of cultivating plants, animals, and other forms of life for food, fibre, and fuel. It broadly consists of the following activities:

- Cultivation of food and textile crops
- Animal husbandry
- Agricultural services.

The agriculture sector is of significant economic importance to both Australia and New Zealand, comprising three percent and five percent of Australia[11] and New Zealand's[12] GDP in 2017 respectively. Agriculture includes and supports a broad range of industries and operators, from advanced large-scale operations to smaller operations which still primarily rely on manual labour from advanced large-scale operations to smaller operations which still primarily rely on manual labour.

8.1.1 Sub-sector descriptions

The agriculture sector is well represented by the SBAS Demonstrator Projects, accounting for seven of the 27 trials undertaken. These trials occurred across the following sub-sectors and activities:

Horticulture

Involves the large-scale harvesting of plants, fruits, and vegetables, which are sold either to be consumed or for gardening. Demonstrator Projects specifically focussed on the vegetable and fruit growing, and viticulture farming component of this sub-sector[13].

Broadacre farming

Technically the broadacre sub-sector refers to farms or industries engaged in the production of grains (wheat, barley, and oats) oilseeds (canola) and other crops (peas, sorghum, maize, hemp, safflower, and sunflower). It also includes the grazing of livestock for meat and/or wool, on a large scale (i.e. using extensive parcels of land)[14]. The Demonstrator Projects for this sub-sector involved grain growing farms only.

Livestock farming

Involves the rearing of animals for food and fibre production. The word livestock applies primarily to cattle (beef and dairy), chickens, goats, pigs, horses, and sheep. Demonstrator Trials involved sheep, beef cattle, and dairy cattle farming.

Forestry

Includes all economic activities that mostly depend on the production of goods and services from forests. This includes commercial activities that depend on the production of raw logs or wood, wood fibre, and non-wood. The Demonstrator Projects for this sub-sector involved the production of raw logs from native forests, hardwood, and softwood plantations.

8.2 Use of positioning technology

Positioning technology has historically been associated with precision farming in the agriculture sector – deploying the optimal and efficient level of effort and product at the right location and time in a manner that results in efficient yields[15].

The use of space-based positioning in agriculture has been used for over 25 years. It was first used as an alternative to radio-based triangulation, in the

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[11] National Farmers Federation (2017) Food, fibre and forestry facts. Retrieved from: https://www.nff.org.au/farm-facts.html

[12] Environment Foundation (2018) Environment guide, agriculture. Retrieved from: http://www.environmentguide.org.nz/activities/agriculture/

[13] Janick, J (2002) Lecture 30: Origins of horticultural science. In: History of horticulture. Purdue University. Retrieved from: https://www.cropsreview.com/what-is-horticulture.html

[14] Organisation for Economic and Cooperative Development (2001) Glossary of statistical terms: broadacre. Retrieved from: https://stats.oecd.org/glossary/detail.asp?ID=235

[15] Mulla, D. and Khosla, R. (2015) A historical evolution and recent advances in precision farming. Included in, Lai, R. and Stewart, B.A (2015) Soil-specific farming: precision agriculture. Retrieved from: https://www.ispag.org/files/Mulla%20and%20Khosla%202015.pdf

form of standalone GNSS. It then gained traction during the 1990s due to the wider coverage afforded and the reduced risk of signals dropping in and around challenging topographies[15]. More recently, DGNSS has proved to be particularly popular with agricultural users, providing up to one metre accuracy.

The primary interest in standalone GNSS for precision farming was initially as a method for identifying the location of harvesting vehicles collecting real-time data on spatial variability in crop yield. Later, interest in the technology shifted to its use in navigating agricultural machinery and autosteering[15].

Since the turn of the millennium, there have been several advancements in positioning technology, such as the augmentation of GNSS using RTK, to deliver centimetre-level precision. In Australia, this technology has primarily been used to deliver improved vehicle guidance in the broadacre cropping sector, particularly in harvesting and seeding[16]. Nevertheless, precise positioning needs are growing in the sector and numerous studies increasingly identifying a broad range of applications which stand to benefit[16,17].

8.2.1 Immature technologies in livestock sector

Unlike some of the other benefits listed in this analysis, the use of location information in the livestock sector for monitoring and tracking animals is in its infancy. Whilst GNSS tracking of livestock in extensive grazing systems has been demonstrated for many years in a research context[18], it is only now emerging as a practical tool for farmers.

The Demonstrator Projects and affiliates spoken to through this process have advised that there are no affordable commercial systems currently available, but there are numerous candidate companies working to deliver on-animal GNSS capabilities.

Challenges remain in the roll-out of spatial technologies in the sector and while producers are currently unclear on the exact way in which GNSS and the SBAS signals may bring value, there is consensus around their potential to benefit the sector.

One of the key limitations of any GNSS use in livestock systems is the form factor (i.e. the size and shape of the collar or ear tag) and energy requirement to run the devices. Whilst many livestock industries would prefer a device the size of an ear tag, the current size of electronic components and batteries mean that size is often limited, thereby slowing down progress.

There is further work to be undertaken in the development of standalone GNSS before the potential benefits of the SBAS signals will be realised. To that end, numerous assumptions around the commercial and operational feasibility of the anticipated livestock sector benefits have been made and are detailed throughout this Chapter.

8.3 Demonstrator Project descriptions

Table AG1 details the Demonstrator Projects involved in trialling the SBAS signals within the agriculture sector.

Table AG1 – Agricultural Demonstrator Projects

Demonstrator project	Description	Signals tested
CQUniversity Australia	Trialling the potential of the SBAS signals to enable automated strip grazing, breeding management, and livestock loss prevention during predation events	L1
CFIG	Exploring the positioning improvements offered by the SBAS signals to Australian farmers for simple positioning tasks and to demonstrate that these improvements can be achieved at low-cost using existing off-the-shelf technologies	L1, DFMC, PPP
Forestry Corporation of NSW	Exploring the benefits of the SBAS signals in driving operational efficiencies and health and safety benefits in the forestry sub-sector	L1, DFMC
Kondinin Group	Exploring operational benefits of the SBAS signals for grain growers within the broadacre	L1, DFMC, PPP

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[16] ACIL Allen (2013) Precise positioning in the agricultural sector. Retrieved from: http://www.ignss.org/LinkClick.aspx?fileticket=iGTBwj8ksjM%3D&tabid=56

[17] Mackenzie, C. (n.d) Precision agriculture and its benefits. Retrieved from: https://www.beeflambz.com/sites/default/files/news-docs/precision-agriculture-and-its-benefits-craige-mckenzie.pdf

[18] Swain, D., Friend, M., Bishop-Hurley, G., Handcock, R. and Wark, T. (2011) Tracking livestock using global positioning systems-are we still lost? Animal Production Science, 51, 167-175.

Demonstrator project	Description	Signals tested
	sub-sector, with a specific focus on operational efficiencies	
Page Bloomer	Exploring the operational benefits of the SBAS signals for apple and vegetable growers in the horticulture sub-sector, with a specific focus on operational efficiencies	L1, DFMC, PPP
Plant and Food Research	Exploring the potential of the SBAS signals for operational efficiencies and yield enhancement in the viticulture sub-sector	L1, DFMC, PPP
Venture Southland	Exploring the potential of the SBAS signals to reduce surveying costs associated with haul road construction within forestry sub-sector	L1, DFMC, PPP

8.4 Anticipated benefits

In attempting to understand the material economic benefits anticipated from greater uptake and utilisation of the SBAS signals in the agriculture sector, a benefits mapping exercise was undertaken with each Demonstrator Project to identify how the benefits of the SBAS signals flowed through to operational benefits.

This led to the identification of a wide variety of benefit categories, as detailed below. Some of these benefits are applicable across multiple sub-sectors (e.g. reduction in spraying overlaps), while some are unique to their sub-sector (e.g. reduced capital investment in forestry haul roads). The following sections detail anticipated benefits by sub-sector.

8.4.1 Horticulture

Efficient deployment of horticulture inputs

Seeds, plants, fruits, and vegetables require a steady supply of nutrients, chemicals (consisting of herbicides, pesticides and fertilisers) and water to aid growth. Precise positioning allows for more accurate spraying with fewer overlaps on each run (defined as a pass with relevant spray application equipment). Without this technology, the combination of reduced positioning awareness and intentional spraying overlap to minimise the risk of under-application, results in over-application of chemicals and fertilisers. According to horticulture sub-sector experts, overlapping of inputs can occur over five to ten percent of the total crop area on farms.

Based on discussion with the sector, it is understood that over-application may lead to crop loss; however, the extent of damage varies significantly across farms, with some experiencing material loss, whilst some experience little to no loss. A key risk, however, is the inefficient use of resources, primarily in the form of inputs, operating expenditure associated with the sprayer, and labour costs of driving the sprayer longer than required. To that end it is anticipated that the SBAS signals will improve the tracking of sprayers, and subsequent inputs, thereby generating operational savings.

Hazard and disease relocation

Currently, considerable time is spent walking amongst crops to identify disease and then relocating these plants to monitor pathological processes. It is anticipated that the SBAS signals will enable farmers to accurately geo-tag plants which have signs of disease (as well as hazards such as broken fences and insect infestations) leading to more time efficient and more effective disease and farm management. This will result in potential labour cost savings for the sub-sector.

Reduction in crop loss to disease

Experts spoken to within the horticulture sub-sector acknowledge that the SBAS signals may serve as an enabler of the mass-market rollout of UAVs within the sub-sector[19]. Among the many benefits enabled by UAV surveying, mapping, and imagery, is the ability to efficiently locate and monitor proxy factors for signs of crop disease[20].

Disease can cause significant losses for farms. For example, viticulture experts suggest that anywhere between five and ten percent of crops can be lost to disease per annum. An enhanced ability to monitor the farm for the early onset of disease is anticipated to limit crop loss, potentially resulting in a prevention of lost revenue.

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[19] The spatial sector Chapter describes the outcomes of a Demonstrator Project that tested the applicability of the SBAS signals to the UAV market.

[20] Dunning, H. (2017) Drones that detect early plant disease could save crops. Retrieved from: https://phys.org/news/2017-04-drones-early-disease-crops.html and https://www.imperial.ac.uk/news/178983/drones-that-detect-early-plant-disease/

Enhanced horticulture yield maps

Yield mapping refers to the process of collecting geo-referenced data on crop yield and its characteristics, such as moisture content, while a crop is being harvested[21]. Using GNSS positioning the yield can be calculated for each location in the field and using a Geographic Information System (GIS) application can be visually displayed on a map.

Evaluating the variation of yield distribution over time within the field is an essential step in defining field areas with potentially high and low yields. This can help to identify spatially variable yield limiting factors and establish yield goals which may inform varying inputs according to field productivity. In simple terms, this means that enhanced spatial mapping enabled by the SBAS signals can identify yield characteristics of crops more effectively thus minimising the risk of over or under application of inputs.

8.4.2 Broadacre

Efficient deployment of broadacre inputs

Similar to horticulture, the SBAS signals are anticipated to enable more precise sprayer and spreader tracking, resulting in a reduction in overlaps when deploying farming inputs. Unlike the horticulture sub-sector, water as an input makes up a smaller portion of total input volumes deployed; however, the use of pesticides, herbicides, and fertilisers remain broadly the same.

Avoided cost of broadacre positioning technology

Many small to medium sized farms within the broadacre sub-sector own or share RTK base stations for the purposes of achieving positioning accuracy levels of between less than 10 centimetres (often via RTK systems).

Deployment of the SBAS signals is anticipated to provide similar levels of accuracy without the need for base stations or subscription costs, which can be viewed as an operating expenditure saving for affected farmers.

Enhanced broadacre yield maps

Similar to horticulture, it is anticipated that the SBAS signals will enable the development of more accurate yield maps, resulting in more efficient deployment of inputs and an overall improvement in yield. Whilst separate research has been undertaken on the potential yield enhancements afforded by yield maps[22], the uptake of that technology remains low due to cost barriers.

Nevertheless, discussion with the sector suggests further exploration of the benefit of SBAS for yield mapping remains warranted due to the potential benefit on offer.

Non-RTK controlled traffic farming

During the lifecycle of a crop many different machines will pass over the field, resulting in most of a farm being driven on at some stage. The compacted soil causes poor plant growth and is costly to restore. CTF allocates separate areas for machinery and plants so optimal conditions are maintained for both driving and growing. The defined wheel tracks provide the best surface for machinery to operate on and all soil compaction is kept to those tracks. The soil spared from being driven on will remain in optimal condition for plant growth, reducing or eliminating the need to cultivate[23].

The more precise the position, the more likely a vehicle will remain on defined wheel tracks. To that end, PPP is anticipated to unlock non-RTK CTF benefits for farms without augmented positioning, potentially resulting in a reduction in cultivation costs and improved yield.

Enablement of inter-row seeding

Broadacre sub-sector experts anticipate the deployment of PPP will enable greater penetration of inter-row seeding within the broadacre sub-sector. In simple terms, inter-row seeding refers to the concept of planting seeds between the prior season's crops, instead of on top of them, to maximise yield.

Decimetre level accuracy afforded by PPP can enable inter-row seeding at a lower cost, which in turn is anticipated to drive down the barrier of entry and encourage greater uptake as well as potentially minimising the impacts of disease carryover on current crop hence maximising yield.

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[21] University of Nebraska-Lincoln (n.d.) Yield monitoring and mapping. Retrieved from: https://cropwatch.unl.edu/ssm/mapping

[22] Ferencz, C. et al (2004) Crop yield estimation by satellite remote sensing. International Journal of remote sensing 25(20):4113-4149 | October 2004.

[23] Bloomer, D. and Hosking, W. (2006) Controlled traffic farming: and the application of high accuracy GPS. Retrieved from: http://www.Page Bloomer.org.nz/wp-content/uploads/Controlled-Traffic-Farming-2006-A5.pdf

8.4.3 Livestock

Efficient pasture utilisation with virtual fencing for dairy

After determining a stocking rate, the second biggest challenge in free-ranging animal management involves optimising pasture utilisation by managing animal distribution.

In some highly productive pastures electric fencing is used to allocate small portions of the total area to the herd. This conventional strip grazing uses electric fences and while very effective at controlling grazing animals and maximising pasture utilisation is highly labour intensive. Virtual fencing (VF) involves the deployment of an on-animal device that controls the location and movement of grazing animals. The accuracy of uncorrected GNSS currently used in VF systems prevents strip grazing.

The high spatial resolution afforded by SBAS as applied to VF is anticipated to enable the development of VF for strip grazing on dairy farms, leading to increased productivity.

Reduced livestock loss from enhanced animal tracking (predation)

The ability to observe and respond to animal behaviour in real-time could help reduce predation events, particularly for sheep. Sheep show distinct behavioural patterns when attacked, including a circling pattern which is a potential indicator that an attack is underway[24]. Current mechanisms for predator management (poisoning, trapping, shooting, and guard dogs) whilst effective provide no real-time alert of attack.

If GNSS tracking systems can be developed for ready deployment on sheep it is anticipated that the increased accuracy in data from an SBAS will allow detection of behaviours indicating predator attacks. In association with the appropriate technology, an SBAS could help alert producers to intervene when an attack is in progress and limit stock loss.

Reduced livestock loss from enhanced animal tracking (illness)

Illness can take a significant toll on animal herds, with research indicating that disease-related issues cost the beef sector alone approximately $941m per annum[25]. Deployment of the SBAS signals in on-animal sensor systems will enable farmers to effectively monitor activity at a much higher spatial resolution enabling improved identification of key behaviours such as lethargy, inactivity or feeding rates, which in turn can provide early indication of illness. Additionally, the location and identification of affected animals will be improved, enabling optimised location and treatment of affected animals.

8.4.4 Forestry

Enhanced forestry geo-referencing

Significant time is expended by forestry owners and contractors in surveying and mapping areas for logging and ensuring that culturally significant sites and/or protected trees are not disturbed. The accuracy provided by the SBAS signals will help operators more accurately geo-tag such trees and sites in real-time, thereby enabling more accurate planning maps for tree felling in less time.

Reduction in forestry related health and safety risks

Enhanced geo-referencing enabled by the SBAS signals is anticipated to reduce time spent mapping and could translate to less time spent in the field by workers. This should reduce exposure to health and safety hazards, ultimately reducing the risk of forestry-related fatalities and serious injuries.

Reduction in forestry related environmental fees and penalties

It is anticipated that the greater spatial resolution afforded by the SBAS signals in and around environmental permit boundaries will reduce the number of infringement notices and fines issued. This benefits the sub-sector by reducing harvesting costs and managing adverse reputational risks of environmental and cultural damage.

Reduced forestry road surveying costs

Forestry operations cover large areas and consist of extensive internal road networks which are used to transport timber. Prior to the construction of these roads, operators undertake a planning process whereby they go on-site to assess and plan the route of a future road. In simple terms, the process

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[24] King, A et al. (2012) Selfish-herd behaviour of sheep under threat. Included in Current Biology, Vol. 22, Issue 14, 24 July 2012. Pages R561-R562. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0960982212005295

[25] Meat and Livestock Australia (2015) Priority list of endemic diseases for the red meat industries. Retrieved from: https://www.mla.com.au/Research-and-development/Search-RD-reports/RD-report-details/Animal-Health-and-Biosecurity/Priority-list-of-endemic-diseases-for-the-red-meat-industries/2895

currently involves the use of standalone GNSS to locate points of interest within the harvest area as they map a route.

The inaccuracies inherent in standalone GNSS mean that operators often undertake a degree of post-processing, which involves data scrubbing, reworking of data collected, and even site revisits; all of which come at an additional cost. The improved accuracy and positioning integrity afforded by the SBAS signals will help reduce the extent of post-processing required, which is anticipated to drive operating expenditure savings within the forestry sub-sector.

Efficient use of forestry riparian margins

Currently, plantations deploy buffer zones around streams and waterbodies to avoid adverse environmental impacts on what are considered environmentally sensitive areas. In practice, operators then place a further buffer on such area (referred to as buffer-on-buffer areas) to compensate for the inherent inaccuracies of standalone GNSS, often unnecessarily limiting the use of high-quality land around water sources. Implementation of the SBAS signals is anticipated to provide greater spatial resolution, which in turn results in the reduction of the buffer-on-buffer areas. This will enable plantations to make better use of land around riparian margins, which could lead to improved yield.

Anticipated benefits have been classified into the following benefit categories as shown in Table AG2.

Table AG2 – Agriculture sector benefit categorisation[26]

Benefit	Benefit category	Quantitative?
	Horticulture	
Efficient deployment of horticulture inputs	Operating expenditure savings	Yes
Hazard and disease relocation	Operating expenditure savings	Yes
Reduction in crop loss to disease	Operating expenditure savings	Yes
Enhanced horticulture yield maps	Operating expenditure savings	No
	Broadacre	
Efficient deployment of broadacre inputs	Operating expenditure savings	Yes
Avoided cost of broadacre positioning technology	Operating expenditure savings	Yes
Enhanced broadacre yield maps	Operating expenditure savings	Yes
Non-RTK CTF	Operating expenditure savings	Yes
Enablement of inter-row seeding	Operating expenditure savings	No
	Livestock	
Efficient pasture utilisation with virtual fencing for dairy	Operating expenditure savings	Yes
Reduced livestock loss via enhanced animal tracking (predation)	Operating expenditure savings	Yes
Reduced livestock loss via enhanced animal tracking (illness)	Operating expenditure savings	No
	Forestry	
Enhanced forestry geo-referencing	Operating expenditure savings	Yes
Reduction in forestry related health and safety risks	Health and safety	Yes
Reduction in forestry related environmental fees and penalties	Environmental	Yes
Reduced forestry road surveying costs	Operating expenditure savings	Yes
Efficient use of forestry riparian margins	Operating expenditure savings	Yes

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[26] Colour coding in Table AG2 has been used to clearly highlight the relevant benefit categories.

8.5 Positioning needs and current methods

The purpose of this section is to detail the positioning needs and current methods employed for all benefits identified. The agriculture sector is experienced with positioning technology in some cases and currently employs standalone and augmented GNSS in many applications. However, each sub-sector has different needs and the spatial requirements for each case need to be evaluated.

Some benefits are already achievable with standalone GNSS technology and are freely available to users who have purchased the appropriate technology. Achieving other benefits requires greater precision and therefore requires augmented GNSS. Currently specialised equipment and subscription fees are mostly limited to large scale operators, who can afford the associated costs.

To frame the remainder of this section, it is worth noting that, at a high level, benefits in the agriculture sector either have a minimum positioning requirement, which is dictated by the inherent nature of the benefit, or a sliding positioning requirement whereby benefits increase (sometimes exponentially) as positioning accuracy increases.

8.5.1 Horticulture

8.5.1.1 Efficient deployment of horticulture inputs

Spray overlap is associated with sections of fields being sprayed multiple times during a spraying operation. The issue arises from fields that are not uniform in shape or size and often include obstacles such as trees, power poles and meandering water courses. Over or under spraying can cause harm to beneficial organisms and accelerate weed resistance to chemicals.

Furthermore, when working on rectangular fields the operator must turn the machine around at the end of the field and the turning area covered by the machine causes gaps of non-sprayed areas. It is customary to use a further pass on the diagonals or headlands of fields to ensure that these areas are sown or sprayed to avoid weed growth and maximise the planting area. This practice means that these areas receive two or three treatments of the inputs[27].

GNSS-based sprayers can track areas which have been treated or sown and turn sprayers off or on to avoid over or under sprayings on field ends or headlands, which in turn can save the input costs of seed, fertilisers, and chemicals, and minimises operation time and wheeling. Wheeling refers to the number of times a farm machine tyre runs over arable farmland. Irregular-shaped fields and obstacles lead to a greater degree of wheeling. Wheeling causes soil compaction and compaction limits crop yields as the soil becomes too dense and does not hold as much water for plants to use. Excessive wheeling therefore reduces yields over time.

The efficient deployment of inputs improves proportionally as positioning accuracy improves. For the purposes of this analysis, three spraying scenarios have been considered:

- Non-precision spraying
- Precision spraying utilising the SBAS signals (specifically PPP)
- Precision spraying utilising RTK

Non-precision spraying is described as a self-propelled spray machine without any form of GNSS guidance assistance or sprayer control. The spray boom consists of multiple zones which can be turned on or off manually. When returning to the field, a farmer can manually turn off the required zones if they assess there is a degree of overlap occurring[28].

Precision spraying systems utilise standalone GNSS and augmented GNSS such as RTK to provide both sprayer guidance and to control sprayer nozzles. A positioning system is used to steer a vehicle, whilst it is also utilised to detect the exact position of each nozzle on the spray boom. The combination of knowing both the sprayer and nozzle's location, enables inbuilt computers to understand where inputs have been applied and automatically shuts off nozzles to avoid overlap[29].

In a RTK system, it is assumed that the upper-bound of potential overlap is five centimetres, corresponding to the level of accuracy enabled. RTK systems come at a cost, which usually involves an RTK system on the machine as well as either purchasing a base station or paying an annual subscription cost to a commercial provider of RTK services.

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[27] Information provided by Demonstrator Project

[28] Batte, M. and Ehsani, M. (2006) The economics of precision guidance with auto-boom control for farmer-owned agricultural sprayers. Retrieved from: https://ageconsearch.umn.edu/bitstream/204877/2/Precision%20Guidance%20-%20COMPAG%20-%20Prepublication.pdf

[29] Information provided by a Demonstrator Project.

For the SBAS signals, the maximum degree of overlap is assumed to be 20 centimetres, based on PPP performance. Whilst this falls short of RTK performance levels, it is better than non-precision spraying and could be of benefit to small-to-medium operations in particular.

8.5.1.2 Disease and hazard relocation

Farms generally sprawl across large areas, which means returning to a point of interest after initial detection can prove difficult (i.e. attempting to relocate an infected tree or broken fence found a week ago). Currently, farmers utilise a combination of manual processes, such as flags or grid maps, and standalone GNSS to attempt geo-referencing of diseases. With a margin of error of ± 10m, use of standalone GNSS means a farmer must still scour an area 20 metres in diameter to relocate an area of interest, which is unlikely to present significant time savings over and beyond manual methods.

With the SBAS signals, the diameter around an area of interest reduces from 20 metres to 20 centimetres (in the case of using PPP), which is likely to reduce labour hours associated with relocation tasks. The potential time savings grow exponentially as accuracy increases in most cases; however, viticulture requires a minimum positioning threshold to be met. This is because vineyard rows must be navigated around if a geo-tag is incorrect.

For example, an inaccurate geo-tag may lead the farmer down the incorrect row, after which the farmer will have to navigate the full length of the adjacent row to assess the other side. Based on this logic, the minimum positioning requirement for geo-tags in viticulture is less than half the required spacing between rows. Based on average row separation of 1.8 metres[30], this results in a 0.9 metre minimum positioning requirement.

8.5.1.3 Reduction in crop loss to disease

Disease can negatively impact on plant health and ultimately lead to crop loss which can adversely impact yield. Discussion with sector experts suggests that farmers could minimise negative impacts on their farms by detecting disease early and in the right locations by utilising UAVs. The specific role of positioning technology is in identifying the spatial position of diseases via accurate geo-referencing of aerial imagery, which is considered a critical enabler of disease detection. UAVs are commonly deployed technology to achieve this goal and its application is described in more detail in spatial sector Chapter 16.

Due to the infancy of UAV usage within the agricultural sector, there is no direct base case with regards to technological disease detection in the market. Based on discussions with the horticulture sub-sector, the primary means of disease detection and monitoring is manual labour. However, technologies such as multi-spectral imaging[31] have begun making small inroads into the sector. Research[32] suggests that decimetre level geo-referencing accuracy is required for such new imagery methods to work effectively and SBAS signals can help achieve this level of accuracy much faster and more efficiently without the need for ground control points.

8.5.1.4 Enhanced horticulture yield maps

Yield maps provide farmers with the information required to better estimate the needs of crops, allowing them to record a history of field performance and make better management choices. The data necessary for the creation of yield maps is typically generated by yield monitoring systems installed in harvesters. These systems generally include three key elements:

- A mass flow sensor, which monitors the volume of crops moving through the harvester.
- A crop moisture sensor, to measure the moisture of the harvested crops. This allows a better estimate of yield and farmers can assess whether the harvest timing was correct and estimate the cost of crop drying.
- A GNSS receiver, providing the spatial positioning required to geo-reference the absolute measurements within the crop.

Once the harvest is complete, the information about the crop mass and moisture is combined with the position on the farmers' computers and processed through GIS to create yield maps, which in turn inform variable rate

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[30] Double A Vineyards (2014) Vineyard design – row orientation, row and vine spacing, and trellis height. Retrieved from: https://doubleavineyards.com/news/2014/02/18/vineyard-design-row-orientation-row-and-vine-spacing-and-trellis-height/

[31] Dunning, H. (2017) Drones that detect early plant disease could save crops. Retrieved from: https://phys.org/news/2017-04-drones-early-disease-crops.html and https://www.imperial.ac.uk/news/178983/drones-that-detect-early-plant-disease/

[32] Assmann, J. et al. (2018) Vegetation monitoring using multispectral sensors – best practices and 4 lessons learned from high latitudes. Draft manuscript. Retrieved from: https://www.biorxiv.org/content/biorxiv/early/2018/05/30/334730.full.pdf

technology (VRT) applications (i.e. machines which adjust the rate of inputs based on yield mapping data as they travel across a farm).

Therefore, enhanced GNSS can help generate higher quality yield maps, which in turn better inform VRT performance and improve overall yields. While the status quo in yield mapping and VRT is sub-decimetre RTK, discussions with sector experts suggest the ability to provide decimetre accuracy using PPP could still provide benefits to the sector, particularly smaller farms which cannot afford costly RTK systems

8.5.2 Broadacre

8.5.2.1 Efficient deployment of broadacre Inputs

The positioning needs and current methods with regards to precision spraying in the broadacre sub-sector are the same as the horticulture sub-sector. More specifically, it is considered there are three scenarios: non-precision spraying, precision spraying using the SBAS signals (specifically PPP), and precision spraying using RTK.

While PPP will not be able to match the sub-decimetre performance of RTK, decimetre level accuracy coupled with its lower barrier to entry relative to RTK is anticipated to unlock precision spraying for small to medium-sized broadacre farms, reducing overlaps down to 20 centimetres.

8.5.2.2 Avoided cost of broadacre positioning technology

It is generally accepted that precision agriculture is of great benefit to not only the broadacre sub-sector, but the agriculture sector as a whole. Farmers deploy an array of positioning technologies to achieve positioning accuracy levels from anywhere between sub-metre level accuracy down to two centimetres.

While some farmers require sub-decimetre level accuracy and are willing to purchase their own base station or subscribe to the necessary services to obtain it. Other farmers find decimetre and sub-metre accuracy sufficient (results from a Demonstrator Project survey show that farmers want under 20 centimetres preferably for all tasks).

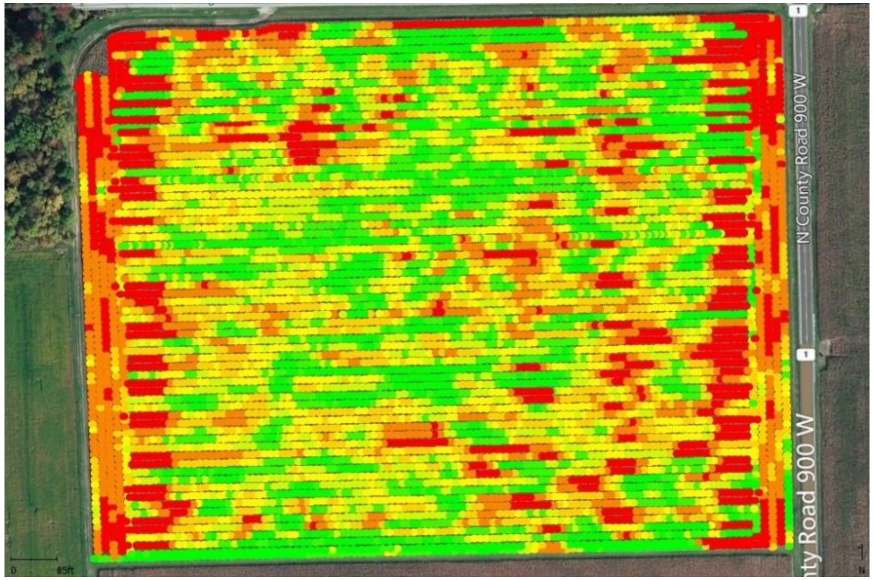
In this case, it is forwarded that operational savings unlocked by these users, in the form of avoided capital costs and subscription costs, are directly attributable to the SBAS signals, provided they can achieve decimetre level accuracy.

8.5.2.3 Enhanced broadacre yield maps

Yield mapping within the broadacre sector works in a similar fashion to the horticulture sector, in that yield monitoring systems are used to track soil characteristics, which are in turn mapped to form yield maps (see Figure AG6[33]).

However, unlike the horticulture sector, economies of scale driven by the expansive nature of broadacre farms make the deployment of VRT more feasible, which means the outputs of yield mapping can be used in a practical manner to improve overall yields. Discussions with the sector and market research[34] suggest that decimetre level accuracy remains sufficient to unlock anticipated benefits associated with VRT use.

Figure AG6 – Example of a yield map



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[33] Nielsen, R.L (2016) Identify and eliminate "gremlins" from yield monitor data. Retrieved from: https://www.agry.purdue.edu/ext/corn/news/timeless/CleaningYieldData.html

[34] Case, I.H. (n.d.) AFS corrections & accuracy. Retrieved from: https://www.caseih.com/northamerica/en-us/products/advanced-farming-systems/auto-guidance/afs-corrections-accuracy

8.5.2.4 Non-RTK controlled traffic farming

Wheeling refers to the number of times a farm machine tyre runs over arable farmland. Irregular shaped fields and obstacles lead to a greater degree of wheeling. Wheeling causes soil compaction and compaction limits crop yields as the soil becomes too dense and does not hold as much water for plants to use. Excessive wheeling therefore reduces yields over time.

CTF involves minimising the footprint of vehicle tracks on a farm. The greater the accuracy of the positioning information fed to driving automation systems, the higher the chance of them staying on pre-defined paths and minimising soil compaction.

The two primary means of achieving necessary positioning standards for CTF are DGNSS and RTK. DGNSS is cheaper than RTK and more accessible; however, it requires establishment of reference stations which can come at a cost. Similar to RTK, correction signals rely on mobile connections or UHF radio, thereby limiting coverage.

The current status quo when it comes to CTF is RTK guided auto-steering which limits movements to the same pathways by a margin of error of ± three centimetres to reduce soil compaction.

Standalone GNSS is considered insufficient for CTF purposes, given that manual driving could perform better than the ± 10 centimetre accuracy of auto-steering. However, it is considered that the ± 20 centimetre accuracy enabled by PPP, will both provide CTF benefits in areas which do not have RTK coverage and to those farmers who cannot afford costly RTK-based CTF systems.

8.5.2.5 Enablement of inter-row seeding

As discussed earlier in this Chapter, inter-row seeding involves the distribution of new seeds between rows containing previously sown seeds. According to discussions with a Demonstrator Project, 10-centimetre level accuracy or less remains sufficient for inter-row seeding, as it allows farmers to sufficiently differentiate between rows.

8.5.3 Livestock

8.5.3.1 Efficient pasture utilisation with virtual fencing for dairy

Virtual fencing involves the use of technology to control the movement of animals across a landscape by providing audio cues and an electrical stimulus that direct the animals and contain them within a permitted area. The permitted locations are programmed remotely and this information is delivered to a device (collar or ear tag) on the animal which uses GNSS to determine where the animal is in relation to the permitted areas.

Several companies are currently developing systems for extensive grazing which use standalone GNSS. These systems employ modelling techniques to reduce the GNSS error, but ultimately the accuracy of standalone GNSS has limited the development of these systems. The spatial accuracy of these systems means that wider virtual fencing error margins must be employed. This makes standalone GNSS viable for larger areas/more extensive systems, but insufficiently accurate for smaller-scale uses.

One promising use of virtual fencing is forage front virtual harvesting (FFVH). FFVH would necessitate far greater accuracy of location than is available through current commercial virtual fencing systems, but the required accuracy could be provided by SBAS signals. While SBAS signals will enable the requisite positioning accuracy, further developments will be required to ensure practical implementation of FFVH in commercial grazing operations.

There are currently no defined minimum standards around positioning accuracy when it comes to using virtual fencing for FFVH. However, it is acknowledged that existing standalone GNSS are unlikely to provide sufficient accuracy. This is because the less accurate the positioning, the greater the difference between individual animal cues received, which will result in an inability to control the herd as a group. Discussion with the Demonstrator Project and sector experts suggest that sub-metre positioning enabled by the SBAS signals will enable virtual fencing systems in Australia and New Zealand to be more practical and enable FFVH. This can increase market penetration and the associated benefits.

8.5.3.2 Reduced livestock loss via enhanced animal tracking (predation and illness)

Tracking animals for the purposes of predation event or illness detection is at the frontier of technology in the livestock sector and as such the understanding around the positioning requirements and methods is immature. There is, however, an understanding of the outcome required to enable the potential avoidance of stock loss during predation events. Research[35] suggests that flocks of sheep, display a centripetal defensive pattern during predation events.

SBAS-enabled GNSS has the potential to more accurately capture this specific behavioural pattern along with other indicators to provide reliable warnings to producers that their animals are under attack.

With regards to detection of ill livestock, discussion with sector experts suggested that sub-metre accuracy would remain sufficient for identifying abnormal movement patterns which would serve as a sufficient proxy.

The ability of SBAS to provide increased accuracy in behavioural modelling has been suggested by sector experts to provide more reliable indicators of a range of issues, one of the most important is disease detection. The key ability of SBAS to provide accurate measures of individual animal movement path metrics (speed and trajectory), animal to feature characteristics (e.g. time spent with head in feed or water trough) and animal to animal interactions (e.g. socialisation metrics) are likely to enable much higher accuracy in inferring a disease state.

8.5.4 Forestry

8.5.4.1 Enhanced forestry geo-referencing

Many benefits in relation to the forestry sub-sector are tied to enhanced forestry mapping. Specifically, the ability to accurately geo-tag environmentally and culturally significant trees, is anticipated to lead to reduced scheduling times, which in turn reduces health and safety risks and reduces environmental damage. Current mapping of trees of significance and riparian margins are undertaken using manual markers, or in some cases, standalone GNSS.

Using manual markers requires a multitude of checks and cross-checks by skilled labourers to ensure the correct trees have been marked and that contractors have not mistakenly cut down the wrong trees. In addition, putting the markers in place takes significant time, effort, and human power leading to an inefficient process. Standalone GNSS is an improvement over manual processes; however, is still prone to error, thereby not completely eliminating cross-check processes and the risk of accidental damage.

The ability to more accurately map riparian margin buffer zones is anticipated to enhance yields by enabling more trees to be planted in a given area. Discussion with the sector suggests that sub-metre accuracy on both fronts is considered sufficient. The sparsely distributed nature of protected trees, along with an average trunk diameter of 0.6 to 1 metre for radiata pine[36] (common plantation tree), suggest that decimetre accuracy is not a necessity for tree mapping and riparian buffers.

8.5.4.2 Reduction in forestry related health and safety risks

Positioning needs and current methods are similar to those noted under the enhanced forestry geo-referencing benefit.

8.5.4.3 Reduction in forestry related environmental fees and penalties

Positioning needs and current methods are similar to those noted under the enhanced forestry geo-referencing benefit.

8.5.4.4 Reduced forestry road surveying costs

Discussion with the forestry sub-sector suggests sub-metre accuracy would be sufficient for improved location of on-ground personnel during route planning. This is important as forest environments can be extremely dynamic with an array of natural features that would have material impact on potential road designs. Anything less than sub-metre accuracy would not provide the spatial granularity necessary to effectively differentiate natural features, such as ledges, which may have an impact on the planning process.

8.5.4.5 Efficient use of forestry riparian margins

According to sector experts, current buffer-on-buffer areas can range anywhere from five to 10 metres. To that end, achieving sub-metre accuracy would enable a significant portion of buffer-on-buffer zones to be reduced and potentially provide operators with the confidence to eliminate such areas all together.

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[35] Manning, J. et al (2014) A pilot study into the use of global navigation satellite system technology to quantify the behavioural responses of sheep during simulated dog predation events. Animal Production Science. 42. Pp 1676-1681.

[36] The wood database (n.d.) Radiata pine. Retrieved from: https://www.wood-database.com/radiata-pine/

8.6 Sector benefits

The following sections detail the benefits of the SBAS signals, relative to the status quo, and shed light on the anticipated economic impacts and how they are attributed across the three signals.

8.6.1 Signal attribution

Table AG3 contains detail around the expected performance of L1, DFMC and PPP within the agriculture sector. As mentioned throughout this Chapter, when it comes to positioning requirements, some benefits are contingent on certain thresholds being met, whilst other benefits improve as positioning accuracy improves. In general, benefits within the horticulture sub-sector require a high level of precision, which lends itself to PPP use. For certain benefits, such as UAV disease detection, a minimum decimetre threshold is required. Other benefits, such as reduced input overlaps and disease tracking, still accrue at sub-metre precision levels, albeit at a diminishing rate.

Based on discussions with the livestock and forestry sub-sectors and FrontierSI, it is suggested that the cost of PPP enabled receivers, coupled with the likely quantity of receivers required for animal tracking would prove too costly to the sector and is anticipated to pose a significant barrier to uptake. To that end, attribution of benefits in the livestock sub-sector has been limited to L1 and DFMC given that sub-metre accuracy is sufficient for animal tracking. A similar line of logic has been applied to the forestry sub-sector, where the cost of PPP receivers is anticipated to prevent uptake and attribution.

Lastly, the anticipated benefits within the broadacre sector revolve around high precision agriculture activities, which can only be provided by PPP.

The indicative test results in Table AG3 have been provided by FrontierSI as representative results of the testing carried out by the SBAS Demonstrator Projects in this sector. Values are presented at a 95 percent confidence interval. Where deviations exist, DFMC SBAS results are expected to be similar to SBAS L1 in an operational system.

The testing was generally carried out in open sky to lightly obstructed environments with professional equipment. All agriculture sector benefits discuss positioning needs for horizontal positioning only.

Table AG3 – Agriculture sector signal attribution

Signal	Agriculture sector test results	
	Expected horizontal performance (m)	Expected vertical performance (m)
L1	0.5	1.1
DFMC	0.6	1.3
PPP	0.2	0.5

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Quantitative benefits					
Efficient deployment of horticulture inputs	Variable	50%	50%	100%	Benefits accrue exponentially as accuracy improves
Hazard and disease relocation	Sub-metre	90%	90%	100%	Minor incremental benefit from decimetre level accuracy
Reduction in crop loss to disease	Decimetre	0%	0%	100%	Multispectral imagery requires decimetre level accuracy
Efficient deployment of broadacre inputs	Decimetre	0%	0%	100%	Requires decimetre level accuracy
Avoided cost of broadacre positioning technology	Decimetre	0%	0%	100%	Requires decimetre level accuracy
Enhanced broadacre yield maps	Decimetre	0%	0%	100%	Requires decimetre level accuracy
Non-RTK controlled traffic farming	Decimetre	0%	0%	100%	Requires decimetre accuracy
Efficient pasture utilisation with virtual fencing for dairy	Sub-metre	100%	100%	0%	Hardware costs for PPP likely to be barrier to uptake
Reduced livestock loss via enhanced animal tracking (predation)	Sub-metre	100%	100%	0%	Hardware costs for PPP likely to be barrier to uptake

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Enhanced forestry geo-referencing	Sub-metre	100%	100%	0%	PPP receiver costs too high for use in forestry
Reduction in forestry related health and safety risks	Sub-metre	100%	100%	0%	PPP receiver costs too high for use in forestry
Reduction in forestry related environmental fees and penalties	Sub-metre	100%	100%	0%	PPP receiver costs too high for use in forestry
Reduced forestry road surveying costs	Sub-metre	100%	100%	0%	PPP receiver costs too high for use in forestry
Efficient use of forestry riparian margins	Sub-metre	100%	100%	0%	PPP receiver costs too high for use in forestry
Qualitative benefits					
Enhanced horticulture yield maps	Variable	✓	✓	✓	Minor incremental benefit from decimetre accuracy
Enablement of inter-row seeding	Decimetre	-	-	✓	Requires decimetre positioning
Reduced livestock loss via enhanced animal tracking (illness)	Sub-metre	✓	✓	-	Hardware costs for PPP unlikely to generate uptake

8.6.2 Uptake

For the purposes of this analysis, the default position is that the SBAS signal uptake across the sector will follow an S-curve, unless stated otherwise. This represents slow initial uptake reflecting early adopters, followed by exponential uptake as the technology is adopted by the mainstream market and then a steady plateau to accommodate late adopters.

The only instances where an S-curve has not been deployed includes the reduced crop loss to disease benefit within the horticulture sub-sector, where full uptake is assumed within five years. This uptake is based on discussion with sector experts, who suggest that demonstrable benefits early on will lead to rapid buy-in from farmers (as has been seen in other industry-benefitting initiatives such as the adoption of screw caps for wine bottles).

In addition, based on historical uptake rates of similar transformative technologies[37], full uptake across the sector is unlikely to occur for every anticipated benefit. Therefore, the uptake rate for the livestock and broadacre sub-sectors have been capped at 80 percent and 60 percent respectively, based on discussions and research from sector experts. An S-curve up to 100 percent over the assessment period has been adopted for the forestry sub-sector.

8.6.3 Quantitative benefits – horticulture

Horticulture is a large sub-sector, which encompasses a variety of produce. Across Australia and New Zealand, the three primary areas of horticulture are fresh fruit, processed fruits, and vegetables.

Operational data for fresh fruit and vegetable farms were sourced from the Demonstrator Project and scaled up using publicly available information. In the case of fresh fruits, operational data from a Demonstrator Project focussed solely on apple orchards and therefore a scaling factor to account for the applicability of these examples has been applied when calculating benefits across the entire fresh fruit market.

Data for processed fruit, which consists solely of viticulture given its over-representation, was sourced and scaled through a variety of publicly available documents and empirical research.

8.6.3.1 Efficient deployment of horticulture inputs

The efficient deployment of inputs resulting from a reduction in chemical spraying due to fewer overlaps is anticipated to result in PV$98m worth of savings to the Australian and New Zealand horticulture sub-sector over 30 years.

In quantifying this benefit, it was important first to understand the reduction in inputs resulting from fewer overlaps in spraying, which then informed operational savings. This included reductions in the cost of materials due to a

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[37] Llewellyn, R. and Ouzman, J. (2014) Adoption of precision agriculture-related practices: status, opportunities and the role of farm advisers. CSIRO December 2014 Report for Grains Research and Development Corporation.

reduction in overlaps, but also labour and equipment cost reductions resulting from a reduction in distance travelled to apply chemicals and fertilisers.

Operating expenditure per hectare and the potential savings for some fruit and vegetable farms were derived from multiple sources, including the relevant Demonstrator Project(s). These per hectare figures were then scaled across all Australia and New Zealand fresh fruit and vegetable farms using a small to medium farm production area as a proxy. In some cases, adjustments were made to account for the applicability of the tested technologies to different crops. For example, a 20 percent discount factor was applied to reflect the limitations of the technology's applicability in the fresh fruits sub-sector (i.e. only 80 percent of the sector will experience the anticipated benefits of SBAS signals), which cannot be used for produce such as kiwifruit, on the advice of a Demonstrator Project.

Second, an assessment of the effectiveness of precision spraying was undertaken. A one percent reduction in overlaps within fresh fruit and vegetable farms was sourced from the Demonstrator Project.

A lack of data for processed fruits meant a peer-reviewed study[38] into the benefits of precision spraying was utilised[39]. The study explored the potential for overlap using non-precision and precision spraying on a 40-hectare rectangular farm. Findings showed an overlap of 1.37 metre for non-precision spraying and only a five-centimetre overlap for precision spraying. The five-centimetre overlap from precision spraying resulted in an overlapped spraying area of 0.1 hectares (0.27 percent) of the total farm area.

Based on these figures it was possible to approximate how a one-centimetre level reduction in overlap could impact on the total overlap area (i.e. dividing the 0.1 hectare overlap area by the five-centimetre input overlap to determine an 'overlap area per cm of input overlap' during a single pass by – 0.022ha/cm). Applied to the 20-centimetre accuracy level anticipated from PPP, this comes out to an expected overlap area of 0.44 hectares (1.10 percent) of a 40-hectare rectangular farm.

The difference between the PPP overlap area and non-precision farming overlap area – seven percent (8.1 percent -1.1 percent = seven percent) – is assumed to be the likely reduction in input overlaps experienced by small to medium scale processed fruit farms which currently do not have access to precision spraying.

Total savings for fresh fruits, processed fruits, and vegetables were then derived by applying this overlap reduction to the total small to medium horticulture production areas across Australia and New Zealand, and by multiplying by a per hectare operational cost. Data used to quantify benefits to the fresh fruit sub-sector were based on apple farms, which was viewed as a sufficient proxy by the Demonstrator Project, and as such an applicability factor of 80 percent has been utilised when applying the data inputs to the wider sub-sector. This recognises that the benefits anticipated within apple farms may not entirely translate to the wider sub-sector, which includes produce such as kiwifruit.

The anticipated benefit from the efficient deployment of inputs from utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG4.

Table AG4 – Reduction in input overlaps (30-year calculation)

Factor	Value	Notes
Total fresh fruit small-medium production area	12m ha	80% of total production for fresh/processed fruits and 30% for vegetables[40]
Total spray operating expenditure	$25b	Includes input costs and sprayer operating expenditure
Anticipated reduction in operating expenditure from reduced overlap	$458m	1% saving anticipated for fresh fruits and vegetable sector and 7% saving for processed fruits
Adjusted for uptake	$384m	S-curve over 30 years

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[38] Batte, M. and Ehsani, M. (2006) The economics of precision guidance with auto-boom control for farmer-owned agricultural sprayers. Retrieved from: https://ageconsearch.umn.edu/bitstream/204877/2/Precision%20Guidance%20-%20COMPAG%20-%20Prepublication.pdf

[39] It is acknowledged that there are differences between this study and the data points being sought. However, this study is considered to be appropriate given the modelling exercise being undertaken.

[40] Please note that this figure has been derived for analytical purposes and represents a sum of the Australian and New Zealand horticulture acreage over a 30-year period (i.e. total current acreage x 30). This has been done as the extent of spray overlaps should be applied annually, not just to one year of production.

Factor	Value	Notes
Present value	$98m	Discounted at 6.5% and including 80% applicability factor for fresh fruits due to use of apple proxy

Note: Totals may not sum due to rounding

8.6.3.2 Hazard and disease relocation

Accurate geo-referencing of hazards or disease in farms is anticipated to save up to 535,000 labour hours, translating to approximately PV$5m in labour cost savings for the horticulture sub-sector over 30 years.

In calculating these savings, the following data points were established through discussion with sector experts:

Hours spent relocating disease or hazards on-site

Data provided by the Demonstrator Project noted that one hour per hectare was spent relocating disease or hazards on-site. A mid-point value of three hours was utilised for processed fruits.

The anticipated labour time savings resulting from accurate geo-referencing

A 33 percent labour time saving was assumed based on feedback provided by the Demonstrator Project.

Labour costs

Assumed to be $32 per hour based on data provided by the Demonstrator Project.

Using a methodology similar to the reduced overlap benefit, the above data for fresh fruits and vegetables was provided by a Demonstrator Project and complemented by research on the operational profile of processed fruits.

In establishing the anticipated reduction in labour hours resulting from accurate geo-referencing, a 33 percent reduction was applied for processed fruits, the same value provided for fresh fruits and vegetables by the Demonstrator Project.

Enhanced geo-referencing of hazards is anticipated to save a total of 14.5m labour hours for the horticulture sub-sector, of which 3.7 percent is attributable to the SBAS signals once considering positioning and the SBAS signals attribution. For the purposes of attribution, it has been assumed that there are three components: handheld device, processing software, and positioning necessary for accurate geo-referencing to be realised. For the positioning component, it is assumed that there are five options available to the farmer: GNSS, DGNSS, RTK, PPP, and the SBAS signals.

Total labour savings due to enhanced geo-referencing enabled by the SBAS signals has then been multiplied by the per hour labour cost, adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG5.

Table AG5 – Reduction in hazard relocation hours (30-year calculation)

Factor	Value	Notes
Total fresh fruit small-medium production area	12m ha[41]	80% of total production for fresh/processed fruits and 30% for vegetables
Hours spent relocating hazards/disease	45m hours	Five, three and one hours per hectare per annum for fresh fruits, processed fruits and vegetables respectively
Total labour hours saved via enhanced geo-referencing	14.5m hours	33% saving anticipated from sector
Total hours saved attributable to positioning	4.5m hours	Assuming three components
Total hours saved attributable to the SBAS signals	960,000 hours	Assuming five options
Adjusted for uptake	535,000 hours	S-curve over 30 years
Total value	$17m	Total labour time savings accrued over 30-year period
Present value	$5m	Discounted at 6.5%

Note: Totals may not sum due to rounding

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[41] Please note that this figure has been derived for analytical purposes and represents a sum of the Australian and New Zealand viticulture acreage over a 30-year period.

8.6.3.3 Reduction in crop loss to disease

The anticipated savings to viticulture forms the bulk of processed fruits in the horticulture sub-sector and is anticipated to be PV$6m over a 30-year period.

Whilst disease detection is a real problem for most of the agriculture sector, identification of disease detection as a specific beneficiary of PPP was only acknowledged in the viticulture sub-sector. As such, benefits of disease detection have been limited to viticulture; however, it is acknowledged that these benefits transcend viticulture and apply across the entire agriculture sector.

Discussion with sector experts suggests that on average, anywhere up to 10 percent of vines are lost to disease on vineyards across Australia and New Zealand per annum. In determining the quantum of vines lost, publicly available viticulture benchmarking reports[42] were analysed to derive an average vine metre (lost to disease) per hectare value. It is important to stress that early disease detection using UAVs is not anticipated to save vines which are already infected, instead it is expected to halt the spread of disease to surrounding vines earlier than might have otherwise been possible.

This value was then applied to the total small-to-medium farm production area to arrive at an estimate of total vine metres across all Australian and New Zealand vineyards.

A mid-point figure of five percent was utilised to determine the portion of vines lost to disease, based on sector estimates, and an exponential early detection success rate was applied to determine the volume of vines which would be saved from early UAV disease detection. This equated to approximately 183m vine metres saved over a 30-year period, of which, 30m vine metres is attributable to the SBAS signals, taking into account UAV components and positioning options available to the market. This final figure was then multiplied by an average gross margin per vine metre value to arrive at a total gross saving.

The anticipated benefit from the reduction in relocation hours from utilisation of the SBAS signals was then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG6.

Table AG6 – Reduction in vines lost to disease (30-year calculation)

Factor	Value	Notes
Total small-medium vineyard vine metres	24b metres[43]	Assuming 4,175 vine metres per ha
Total vines lost to disease	1b metres	5% of total vine metres lost to disease
Total vines saved due to UAV early detection	183m metres	Assuming exponential detection rate up to 27% over 30 years
Total vines saved attributable to positioning	60m metres	Assuming three components
Total vines saved attributable to the SBAS signals	30m metres	Assuming two positioning solutions
Gross value	30m metres	Full uptake by end of year five
Gross margin per vine metre (AUS)	$0.20	Taken from industry data
Gross margin per vine metre (NZ)	$1.5	Taken from industry data
Gross value	$20m	Total savings
Present value	$6m	Discounted at 6.5%

Note: Totals may not sum due to rounding

8.6.4 Qualitative benefits - Horticulture

8.6.4.1 Enhanced horticulture yield maps

Based on discussion with the horticulture sub-sector, it is acknowledged that there are potential benefits associated with enhanced yield mapping enabled by the SBAS signals; however, questions remain over uptake. There is a general understanding that data necessary for yield maps are collected; however, not currently utilised. Given that practical yield maps can be developed using standalone GNSS, it is unclear whether enhanced accuracy

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[42] New Zealand Wine (2017) Variety: gross margin benchmarking. Retrieved from: https://www.mpi.govt.nz/dmsdocument/20144/loggedIn

[43] Please note that this figure has been derived for analytical purposes and represents a sum of the Australian and New Zealand viticulture acreage over a 30-year period.

will result in a step change in uptake over the next 30 years beyond a natural uptake curve.

Nevertheless, whilst it is difficult to provide a definitive figure around potential benefits, research suggests that the potential benefits can be substantial. For example, an Australian study compared the performance of uniform input applications versus a variable rate application informed by yield mapping, resulting in a $25 per hectare cost saving[44]. Other studies[45] suggest that using yield mapping can reduce the volume of chemicals used by 30 to 80 percent, depending on the sophistication of the system used.

8.6.5 Quantitative benefits – Broadacre

For the purposes of this analysis, the broadacre sector has been defined as cropping and/or grain growing farms which focus on summer and winter crops. The analysis has benefitted from two grain growing oriented Demonstrator Projects with significant overlap in anticipated benefits, but a divergence in methodology.

Data provided by one Demonstrator Project (CFIG) have been derived from a survey of 67 farmers in the state of Western Australia, while data provided by another Demonstrator Project (Kondinin) are based on a combination of empirical research articles and survey data of its 8,000 farmer members, from which it received 227 usable responses.

In practice there is some overlap between these two projects, and in some instances, mid-points (or averages) between calculation methodologies have been employed.

8.6.5.1 Efficient deployment of broadacre inputs

The efficient deployment of inputs resulting from less overlaps in chemical spraying is anticipated to result in PV$214m worth of savings to the Australian and New Zealand broadacre sub-sector over 30 years.

To avoid double counting, benefits identified by both Demonstrator Projects have been calculated separately and the mid-point of these two calculations has been used to present the eventual economic benefits. The variability between both methodologies was reasonably narrow (15 percent) which further supports this approach.

One methodology (which took more of a bottom-up approach) determined the benefits to be PV$236m while the other methodology (which was more of a top-down approach) determined the benefits to be PV$191m.

The bottom-up approach distilled survey data to identify the number of small-to-medium scale farmers (less than 6,000 hectares) not using GNSS for spraying and spreading purposes due to either cost, or not being able to achieve 10 to 20-centimetre accuracy. The rationale being that these farmers would benefit most from the roll out of free high-precision GNSS via the SBAS signals.

Based on survey responses, seven percent of a typical broadacre farm is subject to spray overlaps. Taking this as a base case, a six percent reduction factor, derived from the same methodology deployed under section 8.5.1.1, was applied to identify the total reduction in hectares subject to overlap. The total hectares subject to overlap avoided was then multiplied by the average per hectare input cost of $138, as per the survey data, to arrive at the total gross savings to the sector.

The top-down approach used a $3.36 per hectare saving to arrive at a gross saving, applicable to 80 percent of the total harvestable land within the broadacre sector. The $3.36 saving is derived from average fertiliser, pesticide, and herbicide savings (based on sectorial expertise), whilst the 80 percent applicability factor represents the portion of the market not utilising sub five-centimetre RTK based on survey data provided by the Demonstrator Project.

The anticipated benefit from the efficient deployment of inputs from utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG7.

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[44] Cook, S. (1999) Yield mapping: nice maps, how can I use them? Ground Cover Issue 26, 1 March 1999. Retrieved from: https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-26/yield-mapping-nice-maps-how-can-i-use-them

[45] Roberson, G. (2000) Precision agriculture technology for horticultural crop production. Horttechnology, 10(3) July – September. Retrieved from: http://horttech.ashspublications.org/content/10/3/448.full.pdf

Table AG7 – Efficient deployment of broadacre inputs (30-year calculation)

Factor	Value	Notes
Bottom-up		
Total small-to-medium farm hectares not using GNSS due to cost or lack of accuracy	320m hectares	Percent of total hectares that use GNSS <6,000ha farms, multiplied by percent not using GNSS due to cost or inaccuracy (30-year cumulative)
Hectares subject to avoided overlaps	20m hectares	320m hectares x 6% overlap reduction factor
Adjusted for uptake	6m hectares	S-curve up to 60% uptake over 30 years
Total savings	$844m	Hectares subject to overlaps avoided x average per hectare input cost of $138
Present value	$236m	6.5% discount rate
Top-down		
Total cropping area in Australia	830m hectares	Based on statistical data (30-year cumulative)
Total cropping area subject to reduced overlaps	660m hectares	80% of total cropping area - harvestable area
Total savings	$2.2b	Based on per hectare input cost saving of $3.36
Adjusted for uptake	$680m	S-curve up to 60% uptake over 30 years
Present value	$193m	6.5% discount rate
Mid-point		
Mid-point saving from reduced inputs	$214m	Mid-point of CFIG and Kondinin total benefit

Note: Totals may not sum due to rounding

8.6.5.2 Avoided cost of broadacre positioning technology

Avoided costs in relation to capital outlay for RTK base stations and RTK subscription costs for 10 to 20-centimetre level accuracy is anticipated to amount to PV$7m over a 30-year period.

It is important to note here that these farmers are likely receiving accuracy levels less than 10 to 20 centimetres in these instances, but only require accuracy levels between 10 and 20 centimetres.

There are two key sources of savings as a result of the free deployment of PPP: the capital outlay and renewal costs associated with purchasing base stations and RTK subscription costs.

Survey data provided by a Demonstrator Project formed the basis of calculations for this benefit and suggested that approximately 20 percent of broadacre farmers owned their own base station.

In quantifying this benefit, avoided capital costs was applied to the anticipated marginal increase in farmers who would otherwise purchase their own base station on a year-by-year basis. In addition, a 15-year renewal cycle was anticipated and applied to existing and subsequent base station owners for the duration of the 30-year assessment period.

For the purposes of modelling, all farmers were assumed to be purchasing a minimum of one GNSS receiver, ultra-high frequency (UHF) radio with antenna, and an uninterrupted power supply at a cost of $10,000, inclusive of labour and set up costs[46] per farm.

In terms of subscription cost savings, survey data from a Demonstrator Project highlighted that approximately 16 percent of farmers within the broadacre sector paid for subscription services to receive 10 to 20-centimetre level positioning accuracy, at an average annual cost of $1,800.

The summation of base station capital cost savings, base station renewal cost savings, and subscription cost savings provided the total gross savings.

The anticipated benefit from the avoided cost of positioning from utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG8.

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[46] Assumption provided by FrontierSI based on sectorial expertise within the spatial sector.

Table AG8 – Avoided position technology cost saving (30-year calculation)

Factor	Value	Notes
Total cropping area	830m hectares	Based on statistical data (30-year cumulative)
Total number of broadacre farms	210,000	Assuming average farm size of 4,000ha
Total number of farms which own base station	42,000	20% of total farms based on survey data (30-year cumulative)
Incremental increase in farms which own base station over 30-year period	418	Assuming 1% growth rate in line with sector
Capital cost savings (including renewals)	$18m	Assuming 15-year renewal cycle
Total number of farms paying subscription for >10cm accuracy	34,000	16% of total farms based on survey data (30-year cumulative)
Total subscription cost saving	$60m	Based on $1,800 p.a. subscription cost
Total savings	$78m	Base station cost savings plus subscription cost savings
Adjusted for uptake	$24m	S-curve up to 60% uptake over 30 years
Present value	$7m	6.5% discount rate

Note: Totals may not sum due to rounding

8.6.5.3 Enhanced broadacre yield maps

The efficient deployment of inputs resulting from enablement of VRT is anticipated to result in PV$520m worth of operating expenditure savings to the Australian and New Zealand broadacre sector over 30 years.

Empirical research[47] on the benefits of VRT highlights a saving in the range of anywhere from $7 (for small farms) to $22 per hectare (for large farms). These benefits exclude capital costs. For the purposes of this analysis, a weighted average of $14.50 per hectare was utilised as the per hectare operational saving.

According to research[48], approximately 50 percent of all farms already utilise some form of VRT, which leaves another 50 percent as potential customers and beneficiaries of VRT. Based on discussions with a Demonstrator Project, it was anticipated that the deployment of the SBAS signals would lower the cost barrier of VRT technology for the remaining 50 percent of farms and encourage uptake over time.

To that end, the $14.50 per hectare operational saving was applied to 50 percent of all harvestable land, assuming uniform farm sizes for the purposes of modelling, to arrive at a total gross anticipated saving.

The anticipated benefit of enhanced broad acre yield maps from utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG9.

Table AG9 – VRT broadacre saving (30-year calculation)

Factor	Value	Notes
Total cropping area	830m hectares	Based on statistical data (30-year cumulative)
Total cropping area subject to VRT benefits	415m hectares	50% of total cropping area
Total savings	$6b	Based on per hectare cost saving of $14.50
Adjusted for uptake	$1.84b	S-curve up to 60% uptake over 30 years
Present value	$520m	6.5% discount rate

Note: Totals may not sum due to rounding

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[47] Robertson, M., Carberry, P. and Brennan, L. (2009) Economic benefits of variable rate technology: case studies from Australian grain farms. Crop & Pasture Science, 2009, 60, 799-807. Retrieved from: www.publish.csiro.au/journals/cp

[48] Llewellyn, R. and Ouzman, J. (2014) Adoption of precision agriculture-related practices: status, opportunities and the role of farm advisers. CSIRO December 2014 Report for Grains Research and Development Corporation.

8.6.5.4 Non-RTK controlled traffic farming

Enhanced uptake of non-RTK CTF is anticipated to result in PV$250m worth of operating expenditure savings to the Australian and New Zealand broadacre sector over 30 years.

According to sector experts the deployment of PPP within the broadacre sector is anticipated to reduce tyre tracking by 10 centimetres (based on common tyre widths), on average, which equates to approximately 50 square metres of compacted land per hectare and a 35 percent reduction in yield. Utilising a wheat spot price of $250 per tonne results in a $8.80 per hectare in yield losses according to sector experts, which applies to 40 percent of total harvestable land that currently do not use CTF[49].

Multiplying the per hectare operational saving of $8.80 to 40 percent of harvestable land[50] provides the total gross savings anticipated from non-RTK CTF.

The anticipated benefit from enhanced uptake of non-RTK CTF from utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG10.

Table AG10 – Non-RTK CTF saving (30-year calculation)

Factor	Value	Notes
Total cropping area	830m hectares	Based on statistical data (30-year cumulative)
Total cropping area subject to CTF benefits	330m hectares	40% of total cropping area
Total savings	$3b	Based on per hectare cost saving of $8.80
Adjusted for uptake	$900m	S-curve up to 60% uptake over 30 years
Present value	$250m	6.5% discount rate

Note: Totals may not sum due to rounding

8.6.6 Qualitative benefits – broadacre

8.6.6.1 Enablement of inter-row seeding

Inter-row seeding remains an emerging technology within the world of precision agriculture and there remains a lack of conclusive evidence behind projected economic benefits. Notwithstanding this, studies suggest the primary benefit of inter-row seeding is a more productive use of seeds[51], as less seeds are lost to poor planting locations (i.e. on top of a prior years' crop).

A reduction in seed loss, whilst fairly minimal in cost, still has the potential to drive operating expenditure savings for farming operators and have a greater impact on smaller farming operations. Furthermore, inter-row seeding also makes optimal use of soil nutrients and minimises risk of disease (i.e. crown rot) by not planting in the same location every time.

8.6.7 Quantitative benefits – livestock

The benefits presented below represent a combination of empirical research and informed assumptions based on sectorial expertise. They represent a best-case scenario whereby the following assumptions have been made:

- Virtual fencing and predation detection via animal detection are proven to work operationally and commercially for the livestock sector.
- SBAS signals achieve the required performance criteria and serve as the preferred positioning option for livestock farms in the sector. The preference for the SBAS signals is due to the impracticality of alternative precise positioning methods for livestock tracking (i.e. due to receiver sizes or ground infrastructure requirements).

Furthermore, discussions with the livestock sector suggests that 100 percent uptake at the end of the 30-year assessment period is highly unlikely, as no existing technology within the sub-sector has achieved 100 percent uptake. It was agreed that 85 percent is likely to represent the maximum uptake rate, but the speed of uptake will be partially dependent on the transformative impact of the technology.

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[49] Based on data provided by the Demonstrator Project.

[50] Based on survey data provided by the Demonstrator Project.

[51] Mackenzie, C. (n.d) Precision agriculture and its benefits. Retrieved from: https://www.beeflambz.com/sites/default/files/news-docs/precision-agriculture-and-its-benefits-craige-mckenzie.pdf

For the purposes of this analysis, the upper bound of 85 percent has been used as the maximum uptake at year 30 (with an S-curve uptake over the assessment period). This is due to the lack of feasible alternative options (based on existing technology). For example, if the technology is proven, the uptake of predation event detection would likely be rapid due to the significant losses currently experienced by the sheep sub-sector.

8.6.7.1 Efficient pasture utilisation with virtual fencing for dairy

Efficient pasture utilisation by virtual fencing enabled by L1 and DFMC is anticipated to generate approximately PV$780m in savings to the Australian and New Zealand dairy sub-sector over a 30-year period.

While increased pasture utilisation is anticipated to lead to greater costs associated with silage and hay making, to conserve extra forage, discussion with the sector suggests these costs will be more than offset by savings in feed purchases.

In addition, it is assumed that less nitrogen fertiliser would be required, as more strategic application could be enabled via enhanced control of the excretion of nutrients resulting from urine and faeces. Based on discussion with various parties in the sector, the upper bound net savings is anticipated to be in the region of $100 per cow per year, resulting from reduced feed and fertiliser costs.

Emphasis is placed on the term upper bound, as it is acknowledged that such efficiencies would not occur overnight, instead requiring significant organisational and operational change within farms. To that end, an exponential increase in operational savings from $20 to $100 over 30 years is assumed.

This figure is applied to the general dairy cow population across Australia and New Zealand to arrive at a total gross operational saving.

With regards to attribution, it is acknowledged that virtual fencing is an emerging technology and that the SBAS signals will serve as one of many enablers. To that end, it is important to acknowledge additional components which will be required for this benefit to be realised. It is generally believed that virtual fencing will, at a high level, require three components: positioning systems, a behavioural system, and a data transfer system.

It is important to note that based on sector discussion, the benefits of virtual fencing and enhanced grazing management extend to the beef sector too but have not been quantified due to a lack of available data.

The anticipated benefit from efficient pasture utilisation from utilisation of SBAS signal-enabled virtual fencing has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG11.

Table AG11 – Efficient pasture utilisation via virtual fencing for dairy (30-year calculation)

Factor	Value	Notes
Total dairy cow population	362m[52]	Total AUS and NZ population (30-year summation)
Total operating expenditure savings from virtual fencing	$20b	$20 saving per cow per annum up to $100 over 30 years exponentially
Total operating expenditure savings attributable to positioning	$6.6b	Assuming three components
Total operating expenditure savings attributable to the SBAS signals	$5.3b	Assuming L1 and DFMC will be take up 80% of the market
Adjusted for uptake	$3.3b	S-curve over 30 years (capped at 85%)
Present value	$820m	6.5% discount rate

Note: Totals may not sum due to rounding

8.6.7.2 Reduced livestock loss via enhanced animal tracking (predation)

The L1 and DFMC signals are anticipated to enable detection of defensive behaviours among adult sheep during predation events through enhanced livestock tracking, which is anticipated to reduce stock loss to the value of PV$80m over 30 years.

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[52] Please note that this figure has been derived for analytical purposes and represents a sum of the Australian and New Zealand dairy cow herd over a 30-year period. Meat & Livestock Australia (2018) Industry projections 2018: Australian sheep. https://www.mla.com.au/globalassets/mla-corporate/prices--markets/documents/trends--analysis/sheep-projections/revised_2018-jan-mla-australian-sheep-industry-projections-2018.pdf

Early detection of predation events with L1 and DFMC-enabled animal trackers is anticipated to save approximately 39m adult sheep from predators over a 30-year period, of which 6.1m are directly attributable to the SBAS signals.

Unlike most other benefits identified in this sector, predation benefits occur only in Australia as New Zealand lacks any significant predators of sheep. It is also worth noting that predation impacts have only been estimated for adult sheep. Valuation of the likely impact of predation detection in the beef industry for example was not considered here but is feasible and likely to make a financial contribution to the value of SBAS.

The biggest impediment to stopping the loss of sheep to predation events is the ability to detect and react to attacks. Of total adult sheep lost to predators per annum, research suggests that a large proportion of sheep subject to predation display defensive behaviours which, if detected using on-animal sensor technologies, can serve as indicators of the occurrence of predation events[53]. An estimate of 80 percent has been derived and employed in the economic modelling. This proportion has been based on discussions with a Demonstrator Project.

Of these sheep, sector experts anticipate that approximately half can be saved through proactive preventative actions. This equates to approximately 39m adult sheep which can be saved by early detection over the 30-year period.

In acknowledging the role of other components in enhanced animal tracking, specifically data processing and behavioural systems, a 33 percent attribution factor has been applied. This final figure was then multiplied by the average price of ewes to arrive at the total gross operational saving.

The anticipated benefit from reduced stock loss via SBAS signal-enabled animal tracking has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG12.

Table AG12 – Reduction in stock loss from predation (30-year calculation)

Factor	Value	Notes
Total adult sheep population	1.2b[54]	Total Australian population
Total adult sheep lost to predation	96m	8% of total population
Total avoidable adult sheep loss	77m	Based on 80% displaying defensive behaviours
Total adult sheep loss avoided due to early detection	38.5m	Assuming 50% of avoidable sheep loss can be avoided
Total adult sheep loss avoided and sold attributable to positioning and the SBAS signals	13m	Based on three components
Adjusted for uptake	6m	S-curve over 30 years
Total value	$260m	Total value of sheep saved over 30 years
Present value	$80m	6.5% discount rate

Note: Totals may not sum due to rounding

8.6.8 Qualitative benefits - Livestock

8.6.8.1 Reduced livestock loss via enhanced animal tracking (illness)

It is acknowledged that the ability to more accurately track livestock can lead to additional benefits, which are more difficult to quantify given a lack of data within the sub-sector.

Based on discussions with the sub-sector, sudden changes in an individual animal's behaviour could indicate illness and treating the affected animal or destroying it to prevent a wider outbreak (in the case of an emergency disease) both have significant value. Whilst there is a lack of studies which collect data on subtle changes in activity, it remains plausible that improved tracking of animal behaviour, resulting from the SBAS signals, can enable early detection and prevention of disease outbreak.

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[53] Case IH (n.d.) AFS Corrections & Accuracy. Retrieved from: https://www.caseih.com/northamerica/en-us/products/advanced-farming-systems/auto-guidance/afs-corrections-accuracy

[54] Please note that this figure has been derived for analytical purposes and represents a sum of the Australian and New Zealand sheep herd over a 30-year period.

As an example of the scale of potential benefits, an outbreak of foot and mouth disease in New Zealand could cost the economy $16b to $26b over four to five years[55]. Even slight reductions to the risk of an uncontained outbreak could have significant economic benefits.

8.6.9 Quantitative benefits - Forestry

Commercial forest management in Australia and New Zealand occurs in softwood plantations (mainly exotic Pinus species), hardwood plantations (Eucalyptus species) and hardwood native forest (predominantly Eucalyptus species, in Australia only).

Table AG13 provides a summary estimate of the current size of the various forestry areas across Australia and New Zealand.

Table AG13 – Estimate of forestry area in Australia and New Zealand

Forest type	Australia[56]	New Zealand[57]
Softwood plantation	1.0m hectares	1.7m hectares
Hardwood plantation	0.92m hectares	0.4m hectares
Hardwood native forest	5m hectares	-

While these figures represent estimates of the total forestry areas across Australia and New Zealand, the area that is harvestable each year is considerably smaller. Estimates have been derived based on typical harvest ratios provided by a Demonstrator Project and consideration of previous harvest volumes provided in publicly available information. Table AG14 provides an estimate of these values. See the assumptions and limitations section 8.8 for the basis of these estimates.

Table AG14 – Estimate of harvestable forestry areas per annum in Australia and New Zealand

Forest type	Australia	New Zealand
Softwood plantation	34,000 hectares	56,867 hectares
Hardwood plantation	30,667 hectares	13,333 hectares
Hardwood native forest	78,000 hectares	-

It is acknowledged that the underlying size of these forestry areas will change over time, particularly in relation to land-use economics[58]; however, for the purposes of this assessment, no growth in land area has been assumed over the modelling period.

Except for buffer-on-buffer reductions (a reduction in additional operator-led buffer zones around regulatory buffer areas to mitigate risk of infringement), anticipated benefits within the forestry sector apply across commercial forest management activities to varying degrees. For the purposes of presentation, please note that these benefits have been split into softwood plantations and hardwood forest (plantations and native) unless explicitly advised otherwise.

8.6.9.1 Enhanced forestry geo-referencing

Enhanced geo-referencing and mapping of trees of significance is anticipated to save the forestry sub-sector PV$57m in labour cost savings, of which PV$42m is attributable to hardwood forest (native and plantation) and PV$15m is attributable to softwood plantations.

In establishing the quantum of benefits likely to be realised, it is first important to understand not only the scale of labour savings, but also where and how they accrue across hardwood forest (native and plantation) and softwood plantations. Through discussion with sub-sector experts, a list of tasks which would benefit from enhanced geo-referencing was identified. This was then used as the basis for determining the scale of benefits anticipated.

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[55] http://www.stuff.co.nz/business/farming/agribusiness/9890162/Response-all-set-for-any-foot-and-mouth-outbreak

[56] Department of Agriculture and Water Resources (2018). Retrieved from: http://www.agriculture.gov.au/abares/forestsaustralia/Documents/SOFR_2018/Web%20accessible%20PDFs/SOFR_2018_Executive%20summary_web2.pdf?bcsi_scan_01d939382f6c0b14=R+L2ZV2uY0XSYznNOphH7m4OF+CGAAAA0U0nJw==&bcsi_scan_filename=SOFR_2018_Executive%20summary_web2.pdf

[57] Ministry for Primary Industries (2018) New Zealand's forests. Retrieved from: https://www.mpi.govt.nz/news-and-resources/open-data-and-forecasting/forestry/new-zealands-forests/

[58] Including the price of wood and wood products, the cost of labour and other inputs, the price of carbon and the value per hectare for other land-uses.

It is important to note that hardwood native forest operations are often more labour intensive than in softwood plantations due to the extensive ground-based survey and management planning required before harvesting can be undertaken. Therefore, while softwood plantations often represent a larger total harvest volume and value, the proportional difference does not necessarily carry over to labour hours as hardwood native forests require greater labour hours per hectare harvested.

Discussion with the sector suggests the following tasks would benefit in both sectors:

Strategic harvest planning

Forestry owners typically look to develop a strategic long-term plan to answer questions around timing of works, location of works, and scale of works. Enhanced geo-referencing of trees and a reduction in the risk of errors using SBAS signals means less time will be spent cross-checking and reconfirming areas earmarked for harvesting, which is a key input into strategic long-term planning of harvest operations[59].

Softwood plantations anticipated a 25 percent time saving with regards to strategic planning in the form of plan mark-ups and supervising.

Tactical planning

This involves short-term planning focussed around operations and answers questions around methods of harvesting. Benefits are therefore similar to those experienced by strategic harvest planning tasks. Tactical plans are used by contractors on-site and clearer maps mean less time is spent manually cross-checking protected trees against maps and more time is spent harvesting[59]. This means tactical plans can be provided to contractors more quickly, speeding up the tactical planning process.

Hardwood forest (native and plantation) and softwood plantations anticipate an eight percent reduction in labour hours spent doing tactical planning exercises.

Compliance

Regulators utilise maps to audit forestry operations to ensure they comply with regulatory requirements. Clearer maps are anticipated to streamline the work of auditors, thereby minimising operational downtime. Hardwood native forests are anticipated to experience an eight percent reduction in labour hours spent undertaking compliance activities.

Disease and breeding management

Enhanced geo-referencing is anticipated to reduce the time spent identifying areas affected by forest health and nutrition problems, allow operators to better track crops, manage crops, and enable enhanced breeding management.

Softwood plantations anticipate a five percent time saving for disease and tree-breeding management activities.

Sectoral expertise provided by a Demonstrator Project propose that improved maps derived from enhanced geo-referencing would generate between eight to twenty-five percent in time savings across the aforementioned tasks[60]. To scale labour savings across the entire Australian and New Zealand forestry sector, a 'harvested area per labour hour' factor was identified which was then applied to the total sector-wide harvested area.

Determining the difference between the pre-SBAS signal labour cost and post-SBAS signals labour cost provided the gross operational savings.

The anticipated benefit from enhanced geo-referencing from utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG15.

Table AG15 – Enhanced geo-referencing labour savings (30-year calculation)

Factor	Value	Notes
Hardwood forest (native and plantation)		
Total forest area	190m hectares	Total AUS and NZ area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	3.6m hectares	Assuming 3.1% harvested over 30 years for hardwood plantation and 78,000 hectares per annum of hardwood native forest.

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[59] Dykstra, D. (1996) FAO model code of forest harvesting practice. Food and agriculture organization of the United Nations. Retrieved from: http://www.fao.org/docrep/V6530E/V6530E05.htm

[60] Estimates provided by Demonstrator Project.

Factor	Value	Notes
Existing total labour cost	$764m	Site-based planning over 30 years
Enhanced geo-referencing labour cost	$655m	7.5% time saving for site-based planning, harvest supervision, and contract management
Labour cost savings from enhanced geo-referencing	$109m	Based on delta of pre- and post-enhanced geo-referencing
Adjusted for uptake	$55m	S-curve over 30 years
Present value	$42m	6.5% discount rate
Softwood plantation		
Total plantation area	82m hectares	Total AUS and NZ area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	2.5m hectares	Assuming 3.1% harvested over 30 years
Existing total labour cost	$535m	Site-based planning over 30 years
Enhanced geo-referencing labour cost	$495m	5% time saving for disease and breeding management 8% for harvest planning, tactical planning, compliance 25% for plan mark ups and supervising planning
Labour cost savings from enhanced geo-referencing	$40m	Based on delta of pre- and post-enhanced geo-referencing
Adjusted for uptake	$20m	S-curve over 30 years
Present value	$15m	6.5% discount rate
Total		
Total present value	$57m	Hardwood forest (native and plantation) plus softwood plantation

Note: Totals may not sum due to rounding

8.6.9.2 Reduction in forestry related health and safety risks

An economic saving of approximately PV$123m over 30 years is anticipated due to less time spent by forestry workers in live field environments which pose health and safety risks. The benefit comprises PV$68.5m for hardwood forests (native and plantation) and PV$54.5m for softwood plantation forests.

The forestry industry has one of the highest incident rates of all industries across both Australia and New Zealand. The physical demands of the job, the use of heavy machinery, and unpredictable conditions mean it is a high-risk industry[61].

More efficient geo-referencing, mapping, and surveying functions enabled by the SBAS signals mean less worker time is spent on-site, reducing overall risk exposure. By utilising a ‘labour hour per hectare harvested’ proxy derived from data provided by a Demonstrator Project, approximately 27m labour hours were estimated as likely to be spent harvesting forests over the next 30 years across hardwood forest (plantation and native) as well as softwood plantation.

Based on a labour hour per incident proxy factor, derived from Demonstrator Project data, this equated to the potential for approximately 57,000 incidents over 30 years. It is important to note that the term ‘incidents’ is broad and covers minor medical treatment, lost time injuries and fatalities.

Improved geo-referencing, mapping, and surveying is anticipated to generate a time saving reduction of 2.7m labour hours. A combination of Demonstrator Project data and statistical data was used to establish an ‘incident per hectare’ ratio.

This ratio differs by hardwood forest and softwood plantation forest and these specific ratios have been used in the modelling; however, an average figure of 550 labour hours per incident has been adopted. This proxy applied to total labour hours anticipated over a 30-year assessment period equates to approximately 2,700 incidents avoided once adjusted for uptake.

In deriving incident value, a range of data sources has been relied upon. First, a survey of six major forestry companies provided individual cost estimates around costs for minor incidents, serious injuries and fatalities. Table AG16 averages these results.

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[61] Safework Australia (2017) Forestry work. Retrieved from: https://www.safeworkaustralia.gov.au/industry_business/forestry-work

Table AG16 – Avoided health and safety incident value estimate

WHS Incidents	Average (AUD)
Minor incident	$15,000
Serious injury	$206,250
Fatality	$2,633,333

Second, an apportionment of incidents has been estimated using WorkSafe New Zealand data for 2018 as a proxy. This investigation showed that there were seven fatalities and 246 incidents that resulted in a week off work[62].

The seven fatalities have then been subtracted from the 'week off work' figure and the remaining 239 incidents have been apportioned based on a 60:40 (minor incident: serious injury) basis.

Finally, an average incident value of (AUD) $164,000 has been derived applying a weighted average to the above calculations.

The anticipated benefit from less time spent by labourers in live field environments which pose health and safety risks due to utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG17.

Table AG17 – Avoided health and safety risks (30-year calculation)

Factor	Value	Notes
Hardwood forest (native and plantation)		
Total forest area	190m hectares	Total AUS and NZ area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	3.6m hectares	Assuming 3.1% harvested over 30 years for hardwood plantation and 78,000 hectares per annum of hardwood native forest.
Total labour hours pre-enhanced geo-referencing	15m hours	Assuming 8-hour days over 230 operational days
Anticipated labour hour savings	1.9m hours	Average time saving of 13% per task
Total accidents avoided adjusted for uptake	1,500	Based on an incident occurring every 670 hours with an S-curve over 30 years
Gross value	$247m	$164,000 per incident - weighted average of all incidents across the forestry and logging sector
Present value	$68.5	Discounted at 6.5%
Softwood plantation		
Total plantation area	82m hectares	Total AUS and NZ area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	2.5m hectares	Assuming 3.1% harvested over 30 years
Total labour hours pre-enhanced geo-referencing	11.1m hours	Assuming 8-hour days over 230 operational days
Anticipated labour hour savings	840,000 hours	Average time saving of 8% per task
Total accidents avoided adjusted for uptake	1,200	Based on an incident occurring every 350 hours with an S-curve over 30 years
Gross value	$197m	$164,000 per incident - weighted average of all incidents across the forestry and logging sector
Present value	$54.5m	Discounted at 6.5%
Total		
Total present value	$123m	Hardwood plus softwood

Note: Totals may not sum due to rounding

8.6.9.3 Reduction in forestry related environmental fees and penalties

An economic saving of PV$9.5m over 30 years related to reduced environmental fees and penalties is anticipated due to higher quality maps, which are enabled by the SBAS signals. The benefit comprises PV$5.5m for hardwood forest and PV$4m for softwood plantation.

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[62] WorkSafe New Zealand (2019) Data: fatalities. Retrieved from: https://worksafe.govt.nz/data-and-research/ws-data/fatalities/ and Data: injuries resulting in more than a week away from work. Retrieved from: https://worksafe.govt.nz/data-and-research/ws-data/injuries-resulting-in-more-than-a-week-away-from-work/

Based on discussions with the sector it is understood that environmental regulators are especially concerned about activities that occur close to operational boundaries, as defined by resource consents or work permits. The SBAS signals allows for more accurate mapping of this boundary, reducing the risk of environmental incidents.

Data provided by the Demonstrator Project has been used to understand the risk of environmental incidents, which was used to calculate the benefit to the sub-sector.

The proxy factor used for this scaling exercise was the number of hectares harvested per environmental incident, which based on data provided amounted to an incident for every 2,000 hectares harvested. This figure was then used to divide sector-wide harvested area to estimate the total amount of environmental incidents at the boundary across the entire sub-sector (18,000 for hardwood native forest and 13,000 for softwood plantation). These include incidents such as harvesting of trees outside environmental permit area, excavation outside the environmental permit area or working too close to sensitive water bodies. According to sector experts, the average finable incident costs operators $45,000, which reflects legal fees and regulatory fines.

Based on data provided, it is estimated that eight percent of such incidents result in a penalty or require legal defence.

The SBAS signals are anticipated to generate higher quality maps that provide greater spatial resolution at the boundaries. This in turn is anticipated to help avoid approximately 65 percent of such incidents.

The anticipated benefit from higher quality maps due to utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG18.

Table AG18 – Avoided environmental incidents (30-year calculation)

Factor	Value	Notes
Hardwood forest (native and plantation)		
Total forest area	190m hectares	Total AUS and NZ area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	3.6m hectares	Assuming 3.1% harvested over 30 years for hardwood plantation and 78,000 hectares per annum of hardwood native forest.
Total environmental incidents at boundary due to positioning issues	18,275	Assuming an incident occurs for every 2,000 hectares harvested
Proportion of incidents fined	1,370	Assuming 8% get fined based on sector expertise
Proportion of incidents find avoided due to SBAS signals adjusted for uptake	890	65% of fined incidents avoided due to enhanced spatial resolution with S-curve over 30 years
Gross value	$20m	$45,000 per incident (legal fees/fines)
Present value	$5.5m	Discounted at 6.5%
Softwood plantation		
Total plantation area	82m hectares	Total AUS and NZ area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	2.5m hectares	Assuming 3.1% harvested over 30 years
Total environmental incidents at boundary due to positioning issues	13,000	Assuming an incident occurs for every 2,000 hectares harvested
Proportion of incidents fined	975	Assuming 8% get fined based on sector expertise
Proportion of incidents find avoided due to SBAS signals adjusted for uptake	630	65% of fined incidents avoided due to enhanced spatial resolution with S-curve over 30 years
Gross value	$14m	$45,000 per incident (legal fees/fines)
Present value	$4m	Discounted at 6.5%
Total		
Total present value	$9m	Hardwood forest plus softwood plantation

Note: Totals may not sum due to rounding

8.6.9.4 Reduced forestry road surveying costs

The reduction of time spent post-processing, after mapping out prospective forestry road routes, is anticipated to result in PV$10m in savings, with PV$6m accruing to hardwood forests and PV$4m to softwood plantations.

Data provided by a Demonstrator Project suggests reduced post-processing times will result in a 10 percent saving on existing road capital construction costs, which is currently $120 for every hectare of forestry harvested.

The anticipated benefit from reduced post-processing times due to utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG19.

Table AG19 – Forest road cost savings (30-year calculation)

Factor	Value	Notes
Hardwood forest (native and plantation)		
Total forest area	190m hectares	Total AUS and NZ area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	3.6m hectares	Assuming 3.1% harvested over 30 years for hardwood plantation and 78,000 hectares per annum of hardwood native forest.
Total forestry road capital expenditure	$428m	Based on status quo road capital expenditure of $120 per hectare
Capital expenditure savings due to enhanced surveying	$43m	10% saving based on Demonstrator Project data
Adjusted for uptake	$21m	S-curve over 30 years
Present value	$6m	Discounted at 6.5%
Softwood plantation		
Total plantation area	82m hectares	Total AUS and NZ area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	2.5m hectares	Assuming 3.1% harvested over 30 years
Total forestry road capital expenditure	$304m	Based on status quo road capital expenditure of $120 per hectare
Capital expenditure savings due to enhanced surveying	$30m	10% saving based on Demonstrator Project data
Adjusted for uptake	$15m	S-curve over 30 years
Present value	$4m	Discounted at 6.5%
Total		
Total present value	$10m	Hardwood forest plus softwood plantation

Note: Totals may not sum due to rounding

8.6.9.5 Efficient use of forestry riparian margins

Better utilisation of hardwood native forest areas as a result of avoided buffer-on-buffer areas is anticipated to result in PV3m. in savings to the forestry sector over 30 years.

Research shows that hardwood native forests, which are more difficult to manage and plan than plantation forest, lose approximately 2.8 percent of harvestable land to buffer-on-buffer zones[63].

Discussion with the sub-sector suggests that enhanced spatial resolution afforded by the SBAS signals would reduce the need for buffer-on-buffer areas, which would allow better utilisation of existing land.

It is acknowledged that this could result in enhanced yield; however, there are numerous variables which would need to be factored in to accurately quantify potential benefits. Instead, this analysis has focussed on avoided operating expenditure. The rationale being that improved utilisation of land would mean operators needed to prepare less land to harvest the same volume of timber.

It is important to note that hardwood native forest areas are more difficult to plan and harvest due to the terrain and environmentally sensitive natural features. To that end, discussion with the Demonstrator Project suggests that better utilisation of riparian margins remains limited to hardwood native forest.

A blended operational saving per hectare of $300, based on sub-sector feedback, was then used to convert avoided buffer-on-buffer areas into

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[63] Forestry Corporation NSW. (2012) Performance audit report: FRAMES net harvest area modifiers. Retrieved from: http://www.forestrycorporation.com.au/__data/assets/pdf_file/0011/439418/FRAMES-Net-Harvest-Area-Modifiers.pdf

operational savings as this is land that would otherwise need preparation for harvesting.

The anticipated benefit from avoided buffer-on-buffer areas due to utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table AG20.

Table AG20 – Buffer-on-buffer savings for hardwood native forests (30-year calculation)

Factor	Value	Notes
Total hardwood native forest area	150m hectares	Total AUS hardwood native forest area over 30 years (cumulative). See table AG13 for underlying information.
Total harvestable area	2.3m hectares	Assuming 78,000ha is harvested in Australia each year, for 30 years,
Buffer-on-buffer area	65,500 hectares	2.8% of harvestable area subject to buffer-on-buffer area
Adjusted for uptake	32,750 hectares	S-curve over 30 years
Total cost saving	$10m	Based on blended operational cost saving of $300 per hectare
Total present value	$3m	Discounted at 6.5%

Note: Totals may not sum due to rounding

8.7 Summary

Tables AG21 to AG24 contain a summary of benefits, their positioning needs, and the status quo with regards to positioning. Total benefits of **PV AUD$2.2b** are anticipated in the agriculture sector from the deployment of the SBAS signals over a 30-year period. Of the total benefits, 45 percent (**PV$990m**) accrues to the broadacre sub-sector, 41 percent (**PV$900m**) to the livestock sub-sector, nine percent (**PV$203m**) to the forestry sub-sector, and five percent (**PV$110m**) to the horticulture sub-sector.

Table AG21 – Horticulture benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Efficient deployment of horticulture inputs	Variable	Consists of non-precision spraying using manual methods, and precision spraying using RTK	Between 1-7% reduction in input overlaps generating $98m in savings	L1, DFMC, PPP
Hazard and disease relocation	Sub-metre	Currently undertaken manually	535,000 labour hours saved, representing $5m in savings	L1, DFMC, PPP
Reduction in crop loss to disease	Decimetre	Currently no base case due to technology being new. Future base case consists of RTK and cameras	48.4m of vine metres saved at a value of $6m	PPP
Enhanced horticulture yield maps	Variable	Currently not used due to uptake cost	Enhanced accuracy better informs variable inputs which leads to potential operational efficiencies	L1, DFMC, PPP

Table AG22 – Broadacre benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Efficient deployment of broadacre inputs	Decimetre	Wide range of current positioning technologies employed.	Fewer overlaps in chemical spraying is anticipated to result in $214m worth of savings.	PPP
Avoided cost of broadacre positioning technology	Decimetre	RTK used to achieve 10-20cm level accuracy	Avoided base station and subscription costs to the value of $7m	PPP
Enhanced broadacre yield maps	Decimetre	Currently uses RTK to achieve	Improved yields via enablement of VRT	PPP

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
		decimetre level accuracy mapping	generating $520m in savings	
Non-RTK controlled traffic farming	Decimetre	Currently uses RTK to achieve decimetre level accuracy	Improved yields via wider CTF penetration generating $250m in savings	PPP
Enablement of inter-row seeding	Decimetre	RTK system is used as status-quo	Enablement of inter-row seeding can improve yields	PPP

Table AG23 – Livestock benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Efficient pasture utilisation with virtual fencing for dairy	Sub-metre	Currently no base case due to new technology	$820m savings in reduced feed and fertiliser for dairy farms	L1, DFMC
Reduced livestock loss via enhanced animal tracking (predation)	Sub-metre	Currently no base case due to new technology	6m sellable adult sheep saved at a value of $80m	L1, DFMC
Reduced livestock loss via enhanced animal tracking (illness)	Sub-metre	Currently no base case due to new technology	Potential to significantly reduce stock lost to illness via early detection/ prevention	L1, DFMC

Table AG24 – Forestry benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Enhanced forestry geo-referencing	Sub-metre	Manual processes coupled with standalone GNSS	$57m in labour cost savings	L1, DFMC
Reduction in forestry related health and safety risks	Sub-metre	Manual processes coupled with standalone GNSS	2,700 health and safety incidents avoided 'saving' $123m.	L1, DFMC
Reduction in forestry related environmental fees and penalties	Sub-metre	Currently utilises standalone GNSS or manual processes	1,500 environmental incidents avoided at 'saving' of $9m	L1, DFMC
Reduced forestry road surveying costs	Sub-metre	Currently uses specialised and costly surveying equipment	$10m in operational savings related to forestry road construction	L1, DFMC
Efficient use of forestry riparian margins	Sub-metre	Currently utilises standalone GNSS or manual processes	$3m in operational savings via better utilisation of land	L1, DFMC

A range of additional applications in the agriculture sector have been identified throughout this research but have not been quantified (or described qualitatively) for a range of reasons[64]. A collection of these applications is provided in the additional applications Chapter 18.

8.8 Assumptions and limitations

The economic modelling undertaken for this sector has been based on a combination of official data sources, desktop research, information provided by the Demonstrator Project, as well as rational and logical assumptions.

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[64] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

These assumptions have all been agreed in discussion with the relevant Demonstrator Project and FrontierSI.

In addition to standard caveats around economic modelling, the following assumptions and limitations are worth highlighting:

Present value discount

All quantitative benefits have been discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

8.8.1 Horticulture

Reduction in crop loss to disease

UAV disease detection success factor assumed to increase from 10 to 100 percent exponentially over 30 years, reflecting advances in technology.

Farm size distribution

Small-to-medium farm proportion for horticulture modelling purposes assumed to be 80 percent.

Applicability of apple sector benefits to fresh fruit sector

Assumed to be 80 percent. This reflects variability in applicability across different types of fresh fruit and advice from the sector stating apple farm benefits do not translate well to kiwifruit farms, which make a significant portion of New Zealand fresh fruit farms.

Processed fruit labour hours spent relocating hazards

Assumed to be three hours per hectare per year, which is an average of the fresh fruits (five) and vegetable (one) provided by a Demonstrator Project.

Processed fruit reduction in labour hours spent relocating hazards

Assumed to be 33 percent in line with fresh fruits and vegetables as conveyed by Demonstrator Project.

8.8.2 Broadacre

Market growth rate

Assumed to be one percent per annum over the 30-year assessment period across Australia and New Zealand.

Average broadacre farm size

Assumed to be 4,000 hectares for the purposes of establishing total farm counts across Australia and New Zealand.

Base station costs for avoided positioning cost benefit

Farmers assumed to utilise at least one GNSS receiver and a UHF radio with a large antenna and an uninterrupted power supply at a cost of at least $10,000, inclusive of labour costs associated with setting up the base station with the correct reference points and datum.

8.8.3 Livestock

Uptake of operating expenditure savings

Assumed to increase from $20 per dairy cow per year, to $100 over 30 years.

Commercial and operational feasibility

Virtual fencing and predation detection via animal tracking are assumed to be operationally and commercially feasible over the assessment period.

Uptake of technology

The upper bound maximum uptake rate of 85 percent has been adopted to reflect the significance of the problems addressed should the technology work.

8.8.4 Forestry

Proportion of environmental incidents fined

Assumed that 20 percent of environmental incidents are fined per annum.

Anticipated reduction in environmental incidents

Assumed 20 percent reduction in environmental incidents because of enhanced spatial mapping enabled by the SBAS signals.

Estimates of harvestable volumes

It is acknowledged that harvestable volumes will differ on a yearly basis and will differ across geographies and forest types. However, the following assumptions have been employed for the purposes of modelling. These estimates have been derived based on conversations with a Demonstrator Project and investigation into official information provided in Australia and New Zealand.

Softwood plantation and hardwood plantation forest are assumed to operate on a 30-year harvest cycle.

Hardwood native forest has been assumed as operating on a 65-year harvest (mid-point of 30 and 100 years) in deriving the value proxies for use in the modelling. For the total Australian harvest volume, information has been taken from an official publication that noted a total 78,000 hectares were harvested in 2015.

Aviation sector

Key findings

The aviation sector comprises commercial and recreational flight (manned and unmanned) in controlled and uncontrolled airspace. For the purposes of this Chapter the focus areas are commercial passenger transport, air ambulance/hospital transport, and general aviation.

Highlights

The quantifiable economic impact of the SBAS signals in the aviation sector is anticipated to be **PV AUD $404m** over 30 years. These benefits accrue to health and safety, operational, and avoided capital expenditure benefits. A selection of these benefits consists of:

- Reduced risk of CFIT accidents results in reduced loss of life, injury, and loss of airframe. This generates a societal benefit of **PV$284m** over 30 years comprising $246m in safety benefits and $38m of avoided aircraft losses.
- Enhanced access of air ambulances to patients in more remote locations in a wider range of weather conditions results in **PV$52m** of health benefits over 30 years.
- More reliable air travel, with savings of **PV$30m** in direct cost savings to airlines and **PV$38m** in passenger time saved over 30 years.

Quantifiable benefits

Figure AV1 - Benefit by category (30-year, AUD)

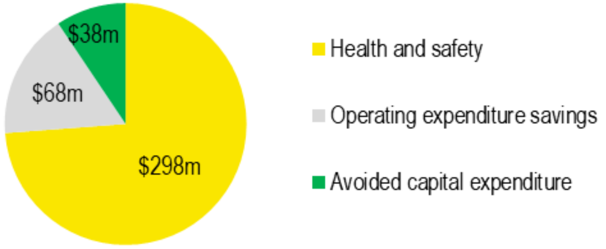


Figure AV2 - Benefit by geography (30-year, AUD)

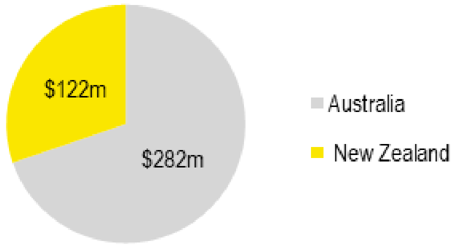
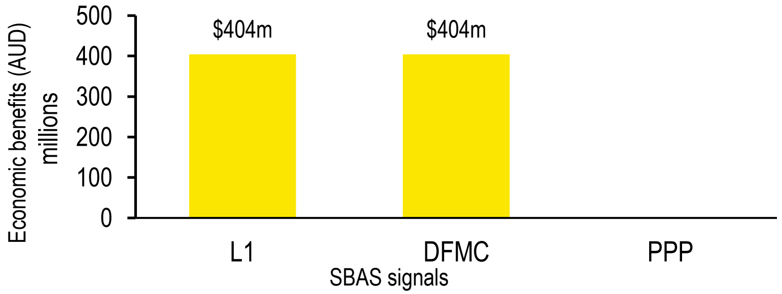


Figure AV3 - Benefit by signal type (30-year, AUD)



9. Aviation sector

9.1 Sector description

The aviation sector is important to both Australia and New Zealand as it facilitates the safe and efficient movement of people and goods between destinations, as well as supporting foreign direct investment. In 2014, the sector contributed 4.5 percent to both Australia's and New Zealand's GDP[65,66].

The aviation sector is quite broad and includes several sub-sectors that stand to benefit from the use of the SBAS signals. The sub-sectors covered in this Chapter are those that stand to gain the greatest benefit from increased vertical accuracy. They are:

Commercial passenger transport

This involves operating an aircraft for hire to transport passengers or multiple loads of cargo to desired destinations. This Chapter primarily focusses on the benefits to non-jet aircraft. These aircraft are the most likely to fly to airports that are not equipped with ILS and can benefit from the SBAS signals.

Air ambulance/hospital transport

Specially equipped aircraft, such as fixed and rotary wing aircraft, operating to transport sick or injured people to the hospital during an emergency. This also includes medical transport flights that transfer patients between medical institutions (e.g. hospitals) where they can receive a different level of care.

General aviation

Private business and travel flights where the purpose of the flight is for the pilot to travel between distinct locations in the course of a business or profession or transport themselves and other occupants and any goods owned by an occupant of the aircraft (e.g. rural veterinary surgeon, engineer, lawyer, doctor or commuting business person), for which the operator and pilot receive no payment for the flight.

9.2 Use of positioning technology

For decades, aircraft and airports have relied on navigation and positioning technology to locate aircraft, manage airspace, and support landings in conditions that cannot be safely completed visually. These include primary (reflective) radar, secondary radar that requests information from aircrafts' on-board transponders, and navigation systems such as ILS.

ILS operates as a ground-based approach system that provides lateral and vertical guidance to aircraft approaching a runway. This technology, in conjunction with other ground infrastructure (e.g. high intensity lighting) can enable safe landings in adverse weather conditions with reduced visibility or low cloud ceilings.

It is widely accepted that landing approaches at airports equipped with ILS are significantly safer and more reliable than those without vertical guidance[67,68]. The SBAS signals have the potential to provide the positioning accuracy and integrity necessary to achieve landings similar to those achievable with ILS at airports and helipads that are not equipped with ILS, enhancing safety and reliability.

Different ILS categories have been defined that allow for different decision heights, approach minima, and runway visual ranges. Decision height refers to the lowest height or altitude during an approach descent at which, if appropriate visual references (e.g. runway markings) cannot be sighted, the pilot must initiate a missed approach. Approach minima describes an altitude and forward visibility requirement, where the pilot must make visual contact with the approach lighting, runway lighting, or runway itself before continuing the approach visually. Runway visual range refers to the distance from which the pilot must be able to see the centreline of the runway. These ILS

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[65] Oxford Economics. (2017a) The importance of air transport to Australia. Retrieved from https://www.iata.org/policy/Documents/benefits-of-aviation-australia-2017.pdf

[66] Oxford Economics. (2017b) The importance of air transport to New Zealand. Retrieved from https://www.iata.org/policy/Documents/benefits-of-aviation-new-zealand-2017.pdf

[67] Ashford, R. (1998) A study of fatal approach-and-landing accidents worldwide, 1980-1996. Flight Safety Digest, February-March 1998, pp 1-41.

[68] Godley, D. and Stuart, T. (2006) Perceived pilot workload and safety of RNAV (GNSS) approaches. Australian Transport Safety Bureau, report number 20050342, December 2006 pp 40-43.

categories require different equipment both on aircraft and on the ground. Category I (ILS CAT I or CAT I) landings – the most common type of precision approach – enables a minimum decision height of 200 feet and a runaway visual range of 800 metres.

The equipment required for ILS is expensive, complex and available only at major airports in Australia and New Zealand. These systems only support a single runway in one direction, although multiple ILS can be installed to provide greater coverage. ILS requires on-ground localisers, which are antenna arrays that transmit signals to supply aircraft with lateral guidance. They also require glide slope stations. These are antenna arrays situated to the side of the runway that provide vertical guidance – the approach angle – to the pilot. ILS flight procedures also require the use of ground-based distance measuring equipment (DME)[69], and in other countries, marker beacons, to provide pilots with a distance indication to the airport.

In New Zealand, only four civilian and two military airfields are equipped with ILS. In Australia, 16 civilian or dual use (i.e. airports with civilian and military uses) and nine military airfields have ILS. The SBAS signals have the potential to act as a backup to existing ILS, act as an alternative to ILS at some airports, and potentially supplant ILS technology in the long term.

GNSS positioning can meet the thresholds required for ILS landings if corrected by Ground-Based Augmentation Systems (GBAS). GBAS provides differential corrections and integrity monitoring of standalone GNSS from the ground, providing the level of accuracy, integrity, and availability required for ILS landings in appropriately equipped aircraft[70]. GBAS is geographically restricted to a small area, however, for example the area immediately surrounding an airport, and uses a Very High Frequency data broadcast to transmit corrections which is not widely available.

Barometric vertical navigation (Baro-VNAV) technology utilises standalone GNSS with data derived from barometric altimetry to support approaches with vertical guidance (APV) in appropriately equipped aircraft, albeit to higher decision heights than are available with the SBAS technology.

However, GBAS and Baro-VNAV are typically installed only on commercial jet aircraft and helicopters. These systems are not available on the vast majority of aircraft that undertake instrument flight operations due to the technical complexity and cost of the systems. Instrument flight operations mean that the aircraft can be operated in a wider variety of conditions, outside of visual flight operations where the pilot must be able to see other aircraft, the surrounding area, and in some cases the ground.

Once the SBAS signals are available and SBAS-enabled receivers are installed, aircraft will be able to complete trips safely in a wider range of weather conditions, including in low cloud. The SBAS signals will also provide for enhanced vertical positioning, enabling pilots to better understand their overall position relative to known hazards (enhanced situational awareness). This will lead to safer flight resulting in a decreased risk of CFIT.

The ability to develop instrument flight procedures to facilitate air ambulance, rescue, and air medical transport services in a wider range of weather conditions (e.g. with low cloud, at night, at airports without navigation aid infrastructure) is also of significant benefit.

This leaves significant scope for the implementation of SBAS signals to provide precise vertical positioning and for the sector to realise benefits from more reliable, safer airspace.

9.3 Demonstrator Project descriptions

Two Demonstrator Projects were commissioned to investigate the potential benefits of the SBAS signals in the aviation sector. The purpose of both projects was to demonstrate the ability of the SBAS signals to enable precision approaches and facilitate lower approach minima. The projects also considered the impact of the SBAS signals on the ability to conduct air ambulance rescues and conduct patient transfers in a wider variety of weather conditions. The main difference between the projects was the focus on minima. Airways New Zealand examined airport specific reductions in approach minima, whereas the Airservices Australia considered whether SBAS approaches were achievable at a variety of Australian airports.

Table AV1 provides a brief description of the Demonstrator Projects considered as part of this Chapter and the SBAS signals used.

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[69] In Australia, GPS-based GNSS may be used in lieu of DME in approved procedures.

[70] Federal Aviation Administration (2018) Satellite navigation – ground based augmentation system (GBAS). Retrieved from: https://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/navservices/gnss/laas/

Table AV1 – Aviation sector Demonstrator Project descriptions

Demonstrator project	Description	Signals tested
Airservices Australia	Demonstration of operational approach guidance capability and static and dynamic performance measurement of SBAS signals. Assessment of demonstrated performance for safety and efficiency benefits for navigation and surveillance.	L1, DFMC
Airways New Zealand	Assessing improvements in vertical guidance and improved SBAS signals approach procedures leading to increased network reliability. Assessing the benefits of enhanced approaches for medical helicopters to selected helipads.	L1, DFMC

9.4 Anticipated benefits

To better document and understand the main economic benefits to the aviation sector anticipated from the SBAS signals, a benefits mapping exercise was undertaken to identify how positioning benefits may be realised operationally. This led to the identification of five health and safety, operational, and capital benefits across both aviation Demonstrator Projects.

Reduced risk of Controlled Flight into Terrain (CFIT)

SBAS signals will allow for enhanced situational awareness. It will also enable the introduction of APV for aircraft that lack Baro-VNAV technology, which is not available to the vast majority of non-airline aircraft

The ICAO states that runway aligned approaches are 25 times safer than non-aligned (circling) approaches and the addition of APV further increases safety margins by a factor of eight[71]. Some aircraft operators consider that enhanced vertical guidance could reduce the rate of CFIT incidents (comprising accidents and near-misses) asymptotically to zero.

The reduced risk of CFIT has safety and capital expenditure benefits. It is expected that the enhanced situational awareness from vertical guidance on approach means that pilots will be able to land safely in a greater range of weather conditions, reducing risks and incidents. This will save lives and reduce the need to replace lost aircraft.

Increased network reliability and the reduction of operating and passenger costs associated with delays, diversions, and cancellations

This is the benefit most directly associated with the implementation of SBAS signals. A report from Aeropath in New Zealand has documented the success of the SBAS test-bed Demonstrator Project, recording reductions in approach minima at several airports. Palmerston North, Nelson, Rotorua, Taupo, Wanaka, and Woodbourne airports benefit significantly from reduced approach minima.[72] It is anticipated that in Australia, the SBAS signals will be of greatest benefit at regional airports that are not already ILS equipped. ILS equipped airports will receive some benefit from SBAS signals, however, as they can serve as a backup for ILS during planned or unplanned outages.

It is expected that the ability to land in a greater range of conditions (particularly where cloud cover is low or visibility is compromised) will allow for a reduction in delays, diversions, and cancellations (DDCs) with benefits to aircraft operation costs and passenger time lost.

Increase in successfully completed rescue and medical flights, leading to reduced morbidity and mortality

Medical helicopter flights and fixed wing medical rescue flights are an important part of the medical systems in both Australia and New Zealand – although New Zealand relies more heavily on helicopter flights than Australia for remote rescue and medivac operations.

The ability to reach incidents quickly, and to rapidly stabilise and transport patients is critical to giving them the highest likelihood of recovery. The SBAS signals will allow for rescue aircraft to land in a wider range of weather conditions, enabling an increase in the number of successfully completed missions.

The increased speed at which patients are rescued is likely to have positive effects on their mortality and morbidity, generating significant societal benefits.

SBAS as a backup system for ILS equipped airports

SBAS is expected to be able to act as a backup for landings at some ILS equipped airports, particularly in Australia. These airports occasionally experience outages of the ILS for relatively short periods (one to two hours),

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[71] ICAO Assembly (2012) Performance based navigation – the implementation challenge. 37th Session, Technical Commission Working Paper A37-WP/148.
[72] Brandt, et al. (2018) SBAS approach concept assessment technical report. Aeropath Ltd. pp 57–58.

due to maintenance, testing or unplanned outages (e.g. ILS equipment lightning strike). During these outages aircraft either cannot land or require the use of different approach procedures. This can lead to air traffic disruption, which could be reduced by the continued operation of SBAS-equipped aircraft.

Increasing capacity and throughput at regional airports

SBAS is expected to enable some regional airports to increase capacity and throughput. The SBAS signals can enable more precise landings in a greater range of conditions at locations where ILS is not economically viable. This will allow greater operational reliability at some regional airports, enabling a greater number of flights and potentially stimulating regional economic investment.

Anticipated benefits in the aviation sector for the purpose of this analysis have been classified into the benefit categories as shown in Table AV2.

Table AV2 – Aviation sector benefit categorisation

Benefit	Benefit category	Quantitative?
Reduced risk of CFIT	Health and safety Avoided capital expenditure	Yes
Increased network reliability and the reduction of operating and passenger costs associated with DDCs	Operating expenditure savings	Yes
Increase in successfully completed rescue and medical flights, leading to reduced morbidity and mortality	Health and safety	Yes
SBAS as a backup system for ILS-equipped airports	Operating expenditure savings	No
Increasing capacity and throughput at regional airports	Operating expenditure savings	No

9.5 Positioning needs and current methods

Due to the global nature of the aviation industry, it is subject to highly standardised regulations, with safety considered a priority. ICAO is the United Nations body responsible for developing standards and recommended practices (SARPs) which prescribe guidance on the required performance of navigation systems. Annex 10 Aeronautical Telecommunications – Volume I Radio Navigation Aids contains the SARPs for SBAS, GBAS, ILS, and other navigation aids.

Vertical guidance provides significant benefits to a range of aviation industry sub-sectors. The minimum navigation performance requirement for approaches with vertical guidance is shown in Table AV3.

Table AV3 – APV Minimum performance requirements

Navigation performance component	Minimum requirement[73]
Vertical accuracy (95 percent)	20m
Integrity	1 - 2 x 10^{-7} per approach
Continuity	1 - 8 x 10^{-6} per 15 seconds
Availability	Over 99%
Time to alert	6 seconds

ICAO standardised the performance of SBAS to meet the intended use in Europe, the United Kingdom, and North America to provide ILS-like navigation services without the need to install local navigation aids. The need to provide approaches lower than 200 ft. was deemed to be unjustifiable due to the significant investment required for the aircraft and aerodrome. There is no indication the situation is different in Australia or New Zealand.

For historical reasons, SBAS-enabled approach procedures are referred to as localiser performance with vertical guidance (LPV). The minimum navigation performance defined above will allow the pilot to conduct an LPV-250, which has approach minima of 250+ feet vertical and forward visibility of 1,200 to

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[73] International Civil Aviation Organization (2018) Annex 10 to the Convention on International Civil Aviation - Aeronautical Telecommunications – volume I, radio navigation aids, seventh edition, July 2018, pp. 3-72.

1,600 metres. LPV-200 approach procedures, with lower landing minima, may be possible after experience with the technology is gained.

The predominant benefits from SBAS accrue due to the ability to achieve precise vertical positioning with integrity at locations and airports that lack ILS and precision approaches. This allows for safer, more reliable approaches at many airports. The following sections describe each benefit and how benefits are currently achieved.

9.5.1 Reduced risk of CFIT

The risk of CFIT while on approach to landing, often due to lapses in situational awareness, is recognised as a significant safety hazard for aviation. CFIT incidents are increasingly rare, partly due to the introduction of runway aligned and performance-based navigation approaches, and partly because of better pilot training and equipment that allows for enhanced situational awareness.

Much of the improvement in CFIT on approach, however, has been attributable to the introduction of precision approaches at a greater number of airports. The ability to achieve further safety gains is limited by the cost of equipment on the ground.

As discussed earlier, there are existing precision ILS technologies that allow for both the vertical and horizontal guidance required to virtually eliminate the risk of CFIT on landing. These technologies are expensive with some ground-based ILS costing $5m to $10m and having operating costs of approximately $50,000 to 60,000 per year[74]. Alternative technologies that can provide continuous vertical guidance like Baro-VNAV also require ground-based infrastructure for pressure and temperature sensing[75,76].

9.5.2 Increased network reliability and the reduction of operating and passenger costs associated with delays, diversions, and cancellations

Approaches have associated approach minima where the pilot must make visual contact with the approach lighting, runway lighting, or runway itself before continuing the approach. In general (terrain permitting) a non-precision approach vertical minimum is between 600 and 800 feet above the runway.

Aircraft cannot land if the visibility is compromised at the decision height. Pilots arriving at airports where visibility is impaired may circle the airport or divert to another airport. When cloud is predicted to be below the decision height at a destination prior to departure, flights will often be delayed or cancelled. This issue primarily affects smaller non-jet aircraft at regional airports, with the vast majority of passenger and cargo jet aircraft in Australia and New Zealand landing at airports with precision approaches.

The SBAS technology supports approaches similar to those enabled by ILS at non-ILS equipped airports and on aircraft that lack Baro-VNAV technology[77]. The SBAS signals provide two key benefits improved (± two to three metre) vertical accuracy, improved protection levels, and signal integrity. The former provides sufficient accuracy to allow for flights with limited visibility even close to terrain, and the latter provides an assurance that pilots are informed when the SBAS signals cannot be relied on for flight operations.

9.5.3 Increase in successfully completed rescue and medical flights, leading to reduced morbidity and mortality

Existing medical rescue and medical transfer flights are conducted primarily by helicopter in New Zealand (e.g. Auckland Rescue Helicopter Trust and HeliOtago). In Australia these flights are conducted by helicopter (e.g. Toll Rescue Helicopter Service) and fixed-wing aircraft (e.g. Royal Flying Doctor Service (RFDS)).

There are several challenges to current operations that can be addressed by the SBAS signals. Helicopter and fixed wing aircraft face different issues and

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[74] Discussions with Airways New Zealand and Airservices Australia.

[75] Federal Aviation Administration (2016) Approval guidance for RNP operations and barometric vertical navigation in the US National Airspace System. Advisory Circular 90-105, March 2016.

[76] Federal Aviation Administration (2011) Guidance for localizer performance with vertical guidance and localizer performance without vertical guidance approach. Advisory Circular 90-107, February 2011.

[77] It is acknowledged that SBAS-only precision landings will require changes to CAA and CASA regulations.

SBAS provides different benefits to the helicopter rescue sector as described in the following sections.

9.5.3.1 Helicopter transport

In New Zealand most remote medical rescue, air ambulance, search and rescue (SAR), and medical transport (e.g. hospital transfers) are conducted by helicopter. It can be challenging landing at many rural locations in poor weather, particularly where the pilot cannot see the ground from a particular height.

There are also benefits with respect to better vertical positioning in challenging terrain, where maintaining a safe buffer between the terrain and the aircraft is difficult using existing equipment. Currently, certain flights (e.g. the route across the mountain ranges between Dunstan and Dunedin hospitals) require that helicopters use large margins to reduce the risk of accidents in challenging terrain. This is largely due to the variability of the terrain and the lack of vertical accuracy provided by current systems.

In the climate of southern New Zealand, icing above the heights required to maintain a safe distance from terrain is common, meaning that flights cannot proceed. With the advent of SBAS, margins can be reduced allowing for flights at lower altitudes. This will enable aircraft to transfer patients and perform rescues in more conditions, as they can fly below the level at which ice can form on rotors.

9.5.3.2 Fixed-wing air ambulance

Fixed-wing aircraft are used in rural areas as air ambulances to transport patients to acute medical services (i.e. hospitals). In some parts of Australia, the ability to provide rescue services is significantly compromised by the inability to land safely during inclement weather. SBAS-enabled APV will improve operational efficiency for these flights due to lower minima at airports with APV procedures, which are not currently available to these aircraft. Additionally, operational safety will be improved by the availability of vertical guidance for the first time, for this class of aircraft at rural and regional locations.

Furthermore, while only a limited number of aerodromes have instrument approach capability, there are a much larger number of small airfields and private airstrips that have basic runway, lighting and aerodrome markings. If adequately surveyed, these facilities could be certified or registered and could then support SBAS APV.

Australia also employs helicopter transport, particularly for inter-hospital transfer and for SAR operations. Consultation with RFDS suggests that the most significant benefit of the SBAS signals will be for their fixed-wing fleet.

9.6 Sector benefits

The following sections detail the benefits of SBAS relative to the status quo, describe the anticipated economic impact, and estimate how benefits are attributed across the three signals.

9.6.1 Signal attribution

Table AV4 contains details on the expected performance of SBAS signals in the aviation sector. L1 and DFMC SBAS signals can provide significant benefits to the aviation sector, but only if signal integrity can be assured. This is currently only available for L1 systems. Signal integrity (SoL assurance) is critical to assure the users that the positioning error is within the specified protection level in both horizontal and vertical directions, and any faults can be identified in real-time, so that alternative (non-SBAS) navigation systems can be used.

Table AV4 describes the realised performance for each SBAS signal, and the benefits attributed to each signal.

These indicative test results in Table AV4 have been provided by FrontierSI as representative results of the testing carried out by the SBAS Demonstrator Projects in this sector. Values are presented at a 95 percent confidence interval. Where deviations exist, DFMC SBAS results are expected to be similar to SBAS L1 in an operational system. Currently, only L1 systems can provide the SoL integrity required for aviation, but this Chapter assumes that DFMC can and will be available for aviation use should it be adopted.

Benefits primarily derive from vertical positioning information, as existing horizontal positioning accuracy is sufficient in most cases.

Table AV4 – Aviation sector signal attribution

Signal	Aviation sector test results	
	Expected horizontal performance (m)	Expected vertical performance (m)
L1	0.7	1.3
DFMC	0.6	1.1
PPP	-	-

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Quantitative benefits					
Reduced risk of CFIT	Metre	100%	100%	-	SoL signal integrity required
Increased network reliability and the reduction of operating and passenger costs associated with weather-related diversions and delays	Metre	100%	100%	-	SoL signal integrity required
Increase in successfully completed rescue and medical flights, leading to reduced morbidity and mortality	Metre	100%	100%	-	SoL signal integrity required
Qualitative benefits					
SBAS as a backup system for ILS equipped airports	Metre	✓	✓		SoL signal integrity required
Increasing capacity and throughput at regional airports	Metre	✓	✓	-	SoL signal integrity required

9.6.2 Uptake rate

No uptake curve has been applied to Australian benefits, as the GNSS navigation avionics fitment mandate of 2016 resulted in very high fitment rate of SBAS capable avionics to General Aviation, and regional aviation, placing the Australian aviation industry in a very good position to adopt L1 systems[78]. However, conversations suggested that it could take some time for SBAS equipment to be installed on larger (jet) commercial passenger aircraft, particularly for DFMC equipment where any significant market penetration is still some years away.

New Zealand also has an ADS-B equipage mandate, but indications from the Civil Aviation Authority New Zealand (CAA) and others suggest that it could take some time for SBAS equipment to be installed on passenger aircraft. The aircraft that are the predominant beneficiaries of this technology are non-jet aircraft, as they more frequently operate at non-ILS equipped airports. Jet aircraft have been excluded from this analysis. Many of these smaller commercial passenger and helicopter rescue aircraft are already equipped for SBAS. Therefore, in New Zealand a linear uptake curve has been employed raising from 50 percent adoption in 2020 to 100 percent in 2025 but it is applied only to non-jet and helicopter aircraft.

Designing approaches that meet required regulatory standards is a necessary precondition for SBAS to be used for landings at airfields and aerodromes. In practice this means that regulators (CAA and Airservices) must design, maintain, and approve SBAS signals approaches prior to the commencement of SBAS enabled LPV approaches at those airfields. Based on discussions with the Demonstrator Projects, it is understood that these approaches can be designed and approved by the time SBAS is anticipated to become operational.

Irrespective of these approaches, SBAS will continue to provide benefits to rescue operations. These operations often take place at makeshift airfields/runways where standard approaches do not exist. The enhanced vertical accuracy enabled by SBAS signals will enable rescues to take place in a wider range of terrain and weather conditions.

9.6.3 Quantitative benefits

Enhanced vertical positioning can contribute to increased safety, particularly on landing, and reduce the risk of CFIT incidents and accidents.

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[78] Information provided by a Demonstrator Project.

As noted earlier in the Chapter, according to Civil Aviation Safety Authority (CASA) in Australia and CAA in New Zealand there have been nine CFIT accidents in Australia resulting from a lack of vertical guidance over the past 20 years, and five in New Zealand over the same period[79,80]. These figures have been tested with aircraft operators and information from similar projects has been used to arrive at assumptions with respect to the number of CFIT incidents per year.

9.6.3.1 Reduced risk of CFIT

Over a 30-year assessment period, it is anticipated that a total of **PV$284m** in health and safety and avoided capital expenditure savings are anticipated from reduced risk of CFIT incidents, directly attributable to the SBAS signals.

There are two components to this benefit: the first represents societal savings as a result of reduction in injuries and fatalities, and the second represents the reduced capital expenditure required to replace aircraft that would be destroyed in CFIT accidents.

Based on the available data, it is estimated that there are two reportable incidents in New Zealand and four incidents in Australia per annum where the safe separation distance between the ground and the aircraft is breached.

These incidents are attributable to a lack of vertical guidance and could result in a CFIT accident. An accident is the realisation of risk from an incident: collision or crash. Confidential data available to the project from CAANZ and published reports suggest that incidents result in accidents only one-tenth of the time[81,82], but those accidents almost always result in loss of life and/or injuries.

9.6.3.2 Fatalities and Injuries from CFIT accidents

Loss of life in a CFIT accident is almost inevitable. Accident reports over the past 30 years show that:

- In New Zealand, each CFIT accident results in an average of 3.7 fatalities and 2.3 injuries.
- In Australia, an average 9.3 people lose their lives in each CFIT accident, and injuries were assumed to occur at the same rate (proportional to fatalities) as in New Zealand (5.9 per accident).

It is anticipated that the use of the SBAS signals in the sector would result in 146 fewer fatalities and 92 fewer injuries over the 30-year analysis period, equating to a societal benefit from reduced injuries and fatalities of PV $246m.

9.6.3.3 Airframe loss from CFIT accidents

In a CFIT accident, the airframe is also lost. Based on consultation with Airservices Australia, a Beechcraft King Air 200T is used as the reference aircraft lost in such an accident. This aircraft has a replacement cost of $5.3m[83]. With SBAS signals, 20 such aircraft would be saved over the 30-year analysis period resulting a capital savings of PV $38m.

9.6.3.4 Reduced risk

Subject to terrain, lighting and runway environments, SBAS signals can support instrument procedure designs enabling virtually the same approach minima as is available at ILS approaches. This allows for approaches similar to that which can be accomplished at ILS-equipped airports, comprising virtually all civilian airports across Australia and New Zealand, which have published and approved SBAS approach procedures, thereby reducing the risk of CFIT incidents.

Separate European studies estimate a 74 percent reduction in CFIT accidents as a result of precision approaches using the SBAS signals. The causes of CFIT accidents are particularly amenable to reduction with SBAS. A 2018 study

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[79] Wackrow, A. (2005) New Zealand fixed wing aviation accidents, Civil Aviation Authority of New Zealand. Retrieved from: https://www.caa.govt.nz/Accidents_and_Incidents/Fxd_wing_accidents_rep.pdf.

[80] Hughes, K. and McRandle, B. (2007) CFIT: Australia in context 1996 to 2005, Australian Transport Safety Bureau. Retrieved from: https://www.atsb.gov.au/media/29968/b20060352.pdf.

[81] Civil Aviation Authority of New Zealand (2016) Aviation safety summary, 1 October to 31 December 2016, Spring 2016. Retrieved from: https://www.caa.govt.nz/assets/legacy/Safety_Reports/2016-q4-Safe-Sum-Rep.pdf

[82] Heintick, H.W. (1959) Industrial accident prevention: a scientific approach. New York: McGraw-Hill Book Company.

[83] Information provided by a Demonstrator Project.

conducted by the International Air Transport Association (IATA) indicates that[84]:

- 51 percent of CFIT accidents were due to navigation aid error or insufficiency
- 46 percent were due to poor visibility
- 33 percent were due to lack of visual reference, the need for which would be reduced in a precision approach
- 21 percent were due to error in manual handling which could be reduced in SBAS precision approaches.

The same report notes that only five percent of all CFIT incidents are due to avionics failure. This data implies that 70 to 85 percent of CFIT accidents could be avoided with the introduction of SBAS. Other studies and industry engagements suggest that 75 percent of CFIT accidents can be avoided[85]. Given the dominance of turboprop aircraft (the principal beneficiaries of SBAS) in the IATA Study's CFIT statistics, an 85 percent reduction has been adopted in this Chapter.

The anticipated benefits as a result of reduced CFIT accidents are presented in Tables AV5 and AV6. Table AV5 shows the SoL benefit from the SBAS signals, and AV6 shows the capital savings benefits. Both values are adjusted for uptake and discounted to present values.

Table AV5 – Reduced risk of CFIT SoL (30-year calculation)

Factor	Value	Notes
Derived number of incidents per annum (Australia)	4	Confidential accident/incident reports provided to EY
Derived number of incidents per annum (New Zealand)	2	Confidential accident/incident reports provided to EY
Incident to accident ratio	0.11	Historical incident to accident ratios derived from confidential data
Average fatalities (New Zealand) per accident	3.7	Historical fatality data
Average fatalities (Australia) per accident	9.3	Historical fatality data
Average injuries (New Zealand) per accident	2.3	Historical injury data
Average injuries (Australia) per accident	5.9	Consultation with Australian aviation industry
Total lives potentially saved	171	Total fatalities as a result of CFIT accidents over 30 years
Total injuries potentially avoided	108	Total injuries as a result of CFIT accidents over 30 years
Value of a statistical injury	$0.71m	NZTA Economic evaluation manual
Value of a statistical life	$3.45m	Value of life
Anticipated reduction in accidents due to SBAS	85%	Based on causes of CFIT and industry engagement
Total fatalities avoided	146	Discounted by the proportion of lives saved due to SBAS
Total injuries avoided	92	Discounted by the proportion of lives saved due to SBAS
Total benefit	$574m	
Present value	$246m	6.5% discount rate

Note: Totals may not sum due to rounding

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[84] International Air Transport Association (2018) Controlled flight into terrain accident analysis report 2008-2017, 2018 edition. Retrieved from: https://www.iata.org/whatwedo/safety/Documents/cfit-report.pdf

[85] ESESA (2010) EGNOS Aviation CBA for AFI, Aviation Workshop 26-27 October 2010 [PowerPoint Slides]. Retrieved from: https://www.gsa.europa.eu/sites/default/files/virtual_library/EGNOS_Aviation_CBA_for_AFI.pdf.

Table AV6 – Reduced risk of CFIT capital losses (30-year calculation)

Factor	Value	Notes
Derived number of incidents per annum (Australia)	4	Confidential accident/incident reports provided to EY
Derived number of incidents per annum (New Zealand)	2	Confidential accident/incident reports provided to EY
Incident to accident ratio	0.11	Historical incident to accident ratios derived from confidential data
Airframe loss	$5.3m	Based on Beechcraft King Air 200T replacement cost
Total aircraft lost to CFIT	20	Estimate of lost aircraft over 30-year period due to CFIT
Anticipated reduction in accidents due to SBAS	85%	Based on causes of CFIT and industry engagement
Total aircraft losses avoided	17	Adjusted for cause and by a linear uptake curve in New Zealand
Total capital costs Avoided	$89m	
Present value	$38m	6.5% discount rate

Note: Totals may not sum due to rounding

9.6.3.5 Increased network reliability and the reduction of operating and passenger costs associated with delays, diversions, and cancellations

Over a 30-year assessment period, it is anticipated that PV$68m in reduced operating and passenger costs associated with DDC can be achieved because of the SBAS signals.

Delays to commercial air operations (in particular) from low cloud is well documented. At airports without ILS or other vertical guidance systems, the landing decision height minimum is between 600 and 800 feet. With the SBAS signals, the decision height can be reduced to as low as 200 to 250 feet terrain, lighting, and runway environments permitting.

This delivers several benefits to the reliability of the network. Flights are more able to operate in adverse conditions (reducing delays and cancellations) and land even if conditions deteriorate when a flight is en-route, resulting in fewer diversions. This generates direct benefits including reduced costs to airlines, reduced passenger delays, and enhanced network reliability.

This analysis focusses exclusively on non-jet aircraft. Larger jet aircraft usually fly out of (and into) ILS-equipped airports, and many do not currently have SBAS technology. This means that the primary benefit from the SBAS signals will be for regional (non-jet) aircraft operating at regional (non-ILS equipped) airports.

9.6.3.6 Delays

Weather delays primarily affect passengers on scheduled flights but may also have an impact on subsequent connecting flights and transfers. In general, delays do not impact overall on operating costs for the airline unless the delays are of sufficient magnitude to require additional capacity to be put on the network.

This analysis assumes that delays only cause passenger disruption. The cost of network disruption is not included in this Chapter. An average delay is relatively short (20 to 90 minutes) in Australia and New Zealand, having limited consequential impacts on network operation. When system-wide delays do occur, the costs and disruption can be significant, but this is usually attributable to large-scale weather events, which are less likely to be amenable to improvement with the SBAS signals.

To determine the delays that could be avoided by the SBAS signals, an analysis of commercial aircraft delays and cancellations was undertaken, along with identifying weather delays that could be addressed by the SBAS signals[86]. Delays and cancellations caused by thunderstorms, high wind, cyclones, and cloud below the minima achievable with the SBAS signals were excluded as these will not be improved as a result of the introduction of the SBAS signals. The analysis also excluded airports equipped with ILS and those where it is impractical or impossible due to terrain to achieve significantly lower minima. This was then reconciled against actual cloud levels across

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[86] The data analysed comprised three years of confidential and commercially sensitive cancellation, delay, and diversion data provided by passenger airlines in Australia and New Zealand.

Australia and New Zealand at airports that were most likely to benefit from SBAS signals. These were also the airports with the most frequent delays and cancellations due to weather (as a result of the relatively high volume of traffic at these aerodromes).

This data was then checked against actual weather data at the time of the flight to understand the number of flights where reduced vertical approach minima would be beneficial. In Australia, depending on the year, 40 to 60 percent of the flights mentioned above would benefit from lower minima (with 50 percent being used in the analysis). In New Zealand, 55 to 75 percent of the flights mentioned would benefit from lower minima, with a value of 65 percent being adopted in this Chapter.

The reduction in delayed flights was applied to average passenger loadings on non-jet aircraft, which are the aircraft that most frequently fly to regional airports, compensating for aircraft type and mix. The exact loading figures are confidential but on average each flight carries 25 to 50 passengers.

The passenger value of time was estimated from the New Zealand Transport Agency (NZTA), Federal Aviation Authority, and Australian sources, and is estimated at $18 per-hour for New Zealand and $28 per-hour for Australia. Passenger value of time is a metric used to determine the value that individuals place on their time and is derived through a combination of survey and wage data. Table AV7 shows the key steps used to calculate the passenger value of time saved due to reductions in delays. Due to the confidential nature of much of the input information, the actual input values and results are withheld.

The number of delays due to low cloud were estimated and the proportion of those delays that could be avoided in Australia and New Zealand were applied. This was then multiplied by average passenger loading and delay time to estimate a total value of passenger delay.

Table AV7 – Reduction of passenger costs associated with delays (30-year calculation)

Factor	Value	Notes
Number of delays due to cloud	Withheld	Confidential data provided by airlines
Proportion of delays avoidable with SBAS (New Zealand)	65%	Calculated based on weather conditions and delay data
Proportion of delays avoidable with SBAS (Australia)	50%	Calculated based on weather conditions and delay data
Passenger loading per flight	25-50	Confidential loading data from airlines and industry benchmarks
Average delay time (minutes)	20-90	Confidential delay data from airlines (range can be disclosed)
Passenger value of time per hour (Australia)	$28	Australian Transport assessment and planning (ATAP) guidelines
Passenger value of time per hour (New Zealand)	$18	NZTA
Passenger value of time saved (delays only)	Withheld	For Australia and New Zealand, uptake using a linear adoption rate for New Zealand only
Present value of Australia and New Zealand passenger value of time saved	Withheld (See DDC summary, Table AV10)	Discounted at 6.5%

9.6.3.7 Diversions

Diversions that can be avoided with the SBAS signals occur for similar reasons to delays, where the cloud base is lower than the approach minima. Diversions account for the majority of direct and travel delay costs in this model as they are more disruptive to passengers and require airlines to reset their networks. A diversion incurs costs due to increased operating time (crew requirements, fuel use, etc.) and the need to reposition the aircraft or reset the network following a diversion.

The network reset may require as many as two additional flight legs to reposition aircraft following a diversion. These are unscheduled flights, often without passengers, making the net cost to the airline particularly high. Depending on the airline they may also incur costs for passenger accommodation and/or alternative transport where feasible.

To estimate the number of avoidable diversions in New Zealand, a similar procedure to that used for calculating delays was employed to estimate the number of diversions that could be avoided with the SBAS signals, based on actual data provided by airlines. This was estimated to be 68 percent.

Comprehensive diversion data was not available for Australia, so an estimate based on international ratios comparing delays, cancellations, and diversions (approximately 75 percent, five percent, 20 percent, respectively)[87] was employed to estimate the likely number of diversions. To do this, the number of cancellations in Australia were multiplied by the values implied by the international ratios to estimate the number of diversions that could be avoided with the SBAS signals. This data was also triangulated using New Zealand ratios, and the results were tested with industry experts who suggested that the number of weather-related diversions in Australia are 30 percent lower than in New Zealand. This led to an estimate that 20 to 30 percent of diverted flights could be avoided with the SBAS signals, with 25 percent used in the calculations.

Based on discussions with industry professionals and previous studies, it was estimated that the average diversion requires an additional two flights to reset the overall network with flight times averaging 1.3 hours in Australia and 1.2 hours in New Zealand. This leads to additional operating costs, which for non-jet aircraft are estimated at a blended rate of $3,150 per hour for a new leg with full crew. For additional flight time, a value of $900 per hour in Australia and $800 hour in New Zealand is used, reflecting the marginal cost of extra travel time when the flight is already in the air (i.e. excludes fixed costs)[88].

Assumptions have also been made about the effect of delays on passengers. Discussions with operators suggest that an arrival delay of three hours be a reasonable estimate for passenger delays if the diversion was to a nearby airport. This value has been used for both Australia and New Zealand. In New Zealand, due to the relatively small scale of the country, buses are often used to finalise the trip for diverted passengers, and the average duration of the bus journey is three hours. The cost to the airline from these bus transfers is confidential but was available to EY for this analysis.

Table AV8 shows the key steps used to calculate reductions in operating and passenger costs due to diversions. As in the previous table, due to the confidential nature of much of the input information, the actual input values and results are withheld.

Table AV8 – Increased network reliability and the reduction of operating and passenger costs associated with diversions (30-year calculation)

Factor	Value	Notes
Number of diversions due to cloud	Withheld	Confidential diversion data proportionally adjusted to account for all domestic regional airlines[89]
Proportion of diversions avoidable with SBAS (Australia)	25%	Consultation with industry experts
Proportion of diversions avoidable with SBAS (New Zealand)	68%	Diversion data combined with weather analysis of New Zealand delay cause
Passenger loading per flight	25-50	Confidential industry data Industry benchmarks
Network reset	2 extra legs required	Consultation with industry and EY assumptions
Flight leg time (Australia)	1.3 hours	Average weighted flight time for Australia
Flight leg time (New Zealand)	1.2 hours	Average weighted flight time for New Zealand
Passenger diversion, trip delay (Australia)	4 hours	Industry assumption regarding average trip delay
Passenger diversion, trip delay (New Zealand)	3 hours	Industry assumption regarding average trip delay

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[87] ESESA (2010) EGNOS Aviation CBA for AFI, Aviation Workshop 26-27 October 2010 [PowerPoint Slides]. Retrieved from: https://www.gsa.europa.eu/sites/default/files/virtual_library/EGNOS_Aviation_CBA_for_AFI.pdf.

[88] New Zealand data provided by CAANZ as part of New Southern Sky programme from Mahino Consulting. Australian adjustments were made based on differences in prevailing labour, fuel, and operating cost rates where available.

[89] Adjustments based on: Domestic airline on time performance reports, Australian Bureau of Infrastructure, Transport, and Regional Economics Jan-Dec 2018 relative to data received from one airline.

Factor	Value	Notes
Cost of bus relocation (New Zealand only)	Withheld	Source withheld
Average direct operating cost (ADOC) per hour	$2,800	Average direct operating cost of turboprop aircraft operated on Australian and New Zealand routes
Marginal in flight ADOC per hour	$800-1,000	Average direct operating cost of turboprop aircraft excluding costs incurred on a per-flight basis (i.e. fully variable costs of operation)
Passenger value of time (Australia) per hour	$28	ATAP guidelines
Passenger value of time (New Zealand) per hour	$18	NZTA Economic evaluation manual
Total avoided cost diversions	Withheld	No uptake curve applied for Australia. Five-year linear uptake applied for New Zealand
Present value	Withheld (See DDC summary, Table AV10)	Discounted at 6.5%

9.6.3.8 Cancellations

The cancellations that can be avoided as a result of the SBAS signals occur when cloud or other adverse weather conditions are present but are not expected to clear within a reasonable window.

In estimating potentially avoided cancellations, a similar approach to that which was used for diversions and delays was employed. Real cancellation data for all weather conditions was tested against a sample of meteorological information from multiple locations to determine the likelihood of a cancellation being due to conditions that could be addressed with the SBAS signals.

Based on available weather and cancellation data, it is estimated that 10 percent of all cancellations could be avoided if the lower approach minima enabled by the SBAS signals were available across Australia and New Zealand.

Cancellations often require one additional flight leg to reset the network and the cost of this additional leg was calculated using a methodology similar to that which is employed for delays and diversions. Cancellations can be more disruptive to passengers, with long delays caused due to the infrequent scheduling of regional flights. It was estimated that a cancellation results in an average delay to passengers of five hours.

There are also likely to be costs to the overall network from cancellations, particularly where they occur in clusters (due to poor conditions over a wide area or a rapidly moving front) – but those consequential system impacts are system wide, multivariate, and highly complex, and are not included in this analysis.

The number of total weather-related cancellations were estimated, and the proportion of those cancellations was multiplied by 10 percent to derive the number of cancellations that could be avoided as a result of the SBAS signals. Country specific data was then multiplied by the additional flight leg time, and the average direct operating cost of a flight to calculate the cost to airlines from a cancellation.

Passenger disruption costs were estimated by calculating the number of cancellations that could be avoided as a result of the SBAS signals, multiplying by estimated passenger loading for those flights, the passenger trip delay estimate, and the country specific value of time.

Table AV9 shows the key steps used to calculate reductions in operating and passenger costs due to cancellations. As in the previous tables due to the confidential nature of much of the input information, the actual input values and results are withheld.

Table AV9 – Increased network reliability and the reduction of operating and passenger costs associated with cancellations (30-year calculation)

Factor	Value	Notes
Proportion of all-weather cancellations avoidable due to SBAS	10%	Analysis of weather data in conjunction with delay data
Cancellations due to weather for airports without ILS, turboprop aircraft only	Withheld	Confidential cancellation data
Passenger loading per flight	25-50	Industry data Industry benchmarks
Network reset	1 extra leg required	EY assumption based on industry consultation
Flight leg time (New Zealand)	1.2 hours	Average weighted flight time in New Zealand
Flight leg time (Australia)	1.3 hours	Average weighted flight time in Australia
Passenger cancellation, trip delay	5 hours	Agreed assumption on consultation with industry on trip delay due to cancellation
ADOC per hour	$3,150	ADOC of a commercial turboprop aircraft (e.g. ATR-72) operated on Australian and New Zealand routes
Marginal in flight ADOC per hour	$800-1,000	ADOC of turboprop aircraft excluding costs incurred on a per-flight basis (i.e. fully variable costs of operation)
Passenger value of time (Australia) per hour	$28	ATAP guidelines
Passenger value of time (New Zealand) per hour	$18	NZTA Economic evaluation manual
Total value of cancellations avoided	Withheld	No uptake curve applied for Australia. Five-year linear uptake applied for New Zealand
Present value	Withheld (see DDC summary, Table AV10)	Discounted at 6.5%

9.6.3.9 Delays, diversions, and cancellations summary

While individual values are withheld to ensure that confidential information cannot be discovered, a breakdown of the aggregate benefits of DDC are provided in summary in Table AV10.

Table AV10 –Increased network reliability and the reduction of operating and passenger costs associated with delays, diversions, and cancellations (30-year, AUD)

Factor	Value
Direct costs to airlines	$38m
Passenger delay time costs	$30m
Total Australian and New Zealand costs avoided	**$68m**

Note: Totals may not sum due to rounding

9.6.3.10 Increase in successfully completed rescue and medical flights, leading to reduced morbidity and mortality

PV$52m in health and safety benefits, because of more completed rescue and medical flights, is possible and attributable to the SBAS signals.

Patients in Australia and New Zealand stand to benefit from the SBAS signals. In both countries a greater number of rescue and hospital transfer flights will be able to occur in more conditions, particularly at night, in low cloud, or (in New Zealand) in freezing conditions.

The potential benefits of the SBAS signals to helicopter ambulance operations in New Zealand are significant. The SBAS signals will allow for the ability to fly through challenging terrain at lower altitudes, meaning that helicopters can fly below the ice level, making flights more reliable throughout the year.

A sample of data provided by one provider shows that more than 30 of the more than 1,000 missions rescue flights are declined each year in Auckland alone due to weather[90]. Thirty to 40 percent of those declined flights were due to cloud cover at heights of 500 to 1,000ft where landings may be possible with the SBAS signals[91].

The latest data showed that 6,589 medical rescue or transfer flights were undertaken in New Zealand in 2015[92]. This was extrapolated to a total number of flights in 2017 of 7,403 based on an historical growth rate of six percent. This means that some 310 flights cannot be completed due to weather each year. Based on the proportion of ambulance to transfer flights, this further implies that some 101 medical flights and 210 transport missions are declined each year due to weather, with approximately 30 percent of those potentially amenable to improvement with the SBAS signals.

Australia has a long history of using fixed-wing aircraft to provide urgent medical care to remote locations. The RFDS South-East (RFDSSE) section provided the number of weather-affected flights in their region, which encompasses most of New South Wales. Approximately 50 patients per annum in the south-east region were unable to receive air ambulance service due to adverse weather conditions that may be amenable to improvement with the SBAS signals. Based on the proportion of the average number of flights in the RFDSSE section per annum (24,400)[93] to the total national number of flights (69,999)[94], EY estimates that approximately 140 ambulance patients and 75 hospital transport patients are affected by adverse weather per annum in Australia. Based on a sample of delay data, it is estimated that 30 to 50 percent of flights would be amenable to improvement with the SBAS signals. Due to the lack of reliable data, however, the improvement has been kept consistent with the anticipated improvement in New Zealand of 30 percent.

The impact of transport delays on these patients is partly determined by the urgency of their medical condition, which is defined by their priority or status code.

According to data provided by an air ambulance operator[95]:

- 12 percent of patients requiring an air ambulance have an immediately life threatening (Status 1) condition, and
- 39 percent have a potentially life-threatening condition (Status 2), of which 20 percent have a time critical need to reach the hospital (due to stroke, etc).

This means that 20 percent of all patients responded to by air ambulance have a time critical need to reach a hospital, where a delay could significantly and adversely affect their health outcomes. Generally, each flight carries only one patient, and this has been assumed for the purposes of this estimate. In some instances, for example motor vehicle accidents or field rescues, multiple patients may be transferred by a single helicopter, so this assumption may generate a slight underestimate.

Transport missions are generally less critical but based on information provided by the RFDS on medical transport, it is estimated that some four percent of patients in Australia and New Zealand have a time critical need for transfer. This often occurs where patients are triaged at a smaller regional facility but require urgent surgery at a larger tertiary hospital.

To estimate the potential patient benefit of more reliable ambulance and hospital transport, an analysis was undertaken considering the impact on patients with a common type of thrombolytic stroke. This allowed for a calculation that provides a very high-level estimate of the scale of benefit that may be anticipated from increased transport and air-ambulance reliability. To have greater confidence in this estimate, it is necessary to have further information on patient conditions, which was not available for this analysis.

A high-level estimate using different disability weights from stroke outcomes is shown in Table AV11. Disability weights represent the degree of disability suffered by an individual due to a medical condition and are used by the World Health Organisation (and others) to support economic evaluation of medical

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[90] Auckland Rescue Helicopter Trust (2017) 2017 Annual report of the Auckland Rescue Helicopter Trust. Retrieved from: https://www.rescuehelicopter.org.nz/library/documents/2017_annual-report_a4_online.pdf

[91] Based on sample logs from Auckland Rescue Helicopter Trust 2009–2016. Provided 2 May 2018.

[92] Correspondence with HeliOtago, referencing ARG report from 2015.

[93] Email from Data Manager, RFDSSE Section. Dated: 19 February 2019.

[94] Royal Flying Doctor Service. (2018) Annual national report of the Royal Flying Doctor Service 2017/18, Responding to need in country Australia. p. 41. Retrieved from: https://www.flyingdoctor.org.au/about-the-rfds/annual-reports/

[95] Email from an air ambulance Medical Director dated 26/06/2018.

interventions. They are represented by DALYs (disability adjusted life years). DALYs indicate the level of disability suffered by an individual in a given year. A value of one represents complete disability (death), and a value of zero indicates no disability. These values can be monetised by multiplying the value of a year of life by the disability weight and the number of years an individual is expected to live with the disability[96].

This high-level estimate relies on a representative individual suffering from a stroke who requires medical evacuation. Hypothetically this person is 75 years old, and suffers a stroke of the type that, with prompt medical attention, results in only a moderate level of ongoing disability. Delays in treatment, however, mean that the individual can allow for the progression of symptoms and greater long-term disability. The difference between suffering ongoing disability at Level 3 (significant impairment) versus Level 2 (moderate impairment) can be a delay in treatment of as little as one to three hours[97].

Actual medical data was not available from the air-ambulance providers, but this analysis provides a scenario with a hypothetical patient cohort to estimate the scale of benefit potentially achievable for the air-ambulance and medical transport sector.

Table AV11 shows the value of improvement in patient health outcomes that could be achieved as a result of faster and more reliable patient transport and rescue if the SBAS signals were adopted.

Table AV11 – Increase in successfully completed rescue and medical flights, leading to reduced morbidity and mortality (30-year calculation)

Factor	Value	Notes
Hypothetical patient (level 2 thrombolytic stroke, 75 years of age)		
Disability weight, chronic stroke - Level 2	0.07	Global burden of disease network
Disability weight, chronic stroke - Level 3	0.316	Global burden of disease network
Disability weight improvement	0.246	
Patients responsive to treatment	20%	tPH (anti-thrombolytic) effectiveness research
Average age at stroke onset	75y	Australian and New Zealand Medical Cohort Research (EY database)
Average life expectancy at 75 (New Zealand)[98]	82y	Average life expectancy of an individual who reaches 75 years old
Value of a DALY	$165,815[99]	Composite estimate converted to AUD
One year of increased quality of life for one patient	$40,790	EY calculation
Increased value of life for one patient living to 85	$252,000	EY calculation, discounted at 6.5%
Patient transport and increased quality of life calculation		
Ambulance flights affected by weather over 30-year	9,295	EY calculation based on RFDS and Auckland Helicopter Rescue Trust (AHRT) data
Transport flights affected by weather over 30 years	6,220	EY calculation based on RFDS and AHRT data
Weather flights amenable to improvement due to SBAS	30%	Sector discussions, and analysis of AHRT and RFDS logs
Ambulance flights completed as a result of SBAS	2,789	Due to the 30% of flights that can now be completed due to the SBAS signals
Transport flights completed as a result of SBAS	1,866	Due to the 30% of flights that can now be completed due to the SBAS signals
Clinically urgent patients (ambulance)	20%	Provided by an air ambulance operator
Clinically urgent patients (transport)	4%	Analysis of RFDS data

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[96] Global Burden of Disease Collaborative Network (2017) Global burden of disease study 2016 (GBD 2016) Disability weights. Seattle, United States: Institute for Health Metrics and Evaluation (IHME).

[97] Bivard, A. et al. (2013) Review of stroke thrombolytics. Journal of Stroke. 2013 May 15(2), 90-98.

[98] Statistics New Zealand (2017) Abridged life table for 2015-17. Retrieved from: https://www.stats.govt.nz/information-releases/new-zealand-abridged-period-life-table-201517-final

[99] O'Dea, D. and Wren, J. (2012) New Zealand estimates of the total social and economic cost of injuries. Report to New Zealand Injury Prevention Strategy. Wellington, New Zealand. p 42.

Factor	Value	Notes
Patients with improved outcomes over 30 years	519	EY calculation based on number of flights completed, effectiveness of treatment.
Australian and New Zealand improved health outcomes	$130m	No uptake curve for Australia. New Zealand uses a 5-year, linear uptake
Present value	$52m	Discounted at 6.5%

Note: Totals may not sum due to rounding

9.6.4 Qualitative benefits

There are also likely to be further reliability and capacity benefits to the sector that were not easily quantified due to the limited data available.

The two main benefits are:

- SBAS signals could provide redundancy to the aviation system in the event of a planned or unplanned ILS blackout
- SBAS could support greater capacity and increased at regional airports, particularly those facing large increases in traffic.

9.6.4.1 SBAS as a backup system for ILS equipped airports

Some ILS equipped airports may benefit from the SBAS signals as a backup to ILS in the case of outages. One major Australian airport reports that ILS outages occur between once and twice a year and can last from 15 minutes to one hour.

This outage duration may seem trivial, but during this period landings are significantly slowed or stopped, depending on weather conditions. This can lead to a backlog of as many as 50 aircraft, which can take hours to clear after the restoration of ILS.

SBAS signals provide the necessary accuracy and integrity to act as a backup for ILS in most situations and could allow for continued airport operations even in the case of ILS outages due to equipment failure or scheduled maintenance. This is relevant at the 20 civilian airports that operate ILS in Australia and New Zealand, and accounts for a significant majority of commercial air traffic in both countries.

9.6.4.2 Increasing capacity and throughput at regional airports

Many smaller airports cannot afford the capital and ongoing operational costs of ILS, which could mean that they are less reliable and less attractive than larger airports which are better equipped. Despite this, volume at some small airports is increasing, particularly in Australia where regions are distant, but often have relatively large population bases. Armidale Airport in New South Wales is one such airport. The following case study shows how the SBAS signals can support regional development and the promise that this system can increase safety and reliability at airports that otherwise would be unable to economically install ILS. Other airports are also likely to use SBAS, with many of the larger regional airports likely to consider SBAS as an alternative to ILS.

Case study: Benefits to Armidale Airport from SBAS[100]

The city of Armidale is located in the picturesque New England High Country of New South Wales. At the hub of a vibrant regional economy, Armidale is renowned as a leading centre for higher education, tourism, agriculture, business, sporting, and leisure activities.

With passenger numbers doubled in little more than a decade, Armidale Airport looks to larger aircraft, such as QantasLink's Q400, and multiple operators, including Regional Express (Rex) and Fly Corporate, to satisfy airline demand. However, the airport also views new airline routes, flying training and business and general aviation as key components in supporting the region's appeal to business and holiday visitors.

Phillip Perram, Service Leader Business Units for Armidale Regional Council, is focused on opportunities for the airport to better serve the community. "Our immediate plans include facilities to support 140,000 passengers each year, with two new airline routes and a flying school" he explained. Armidale Regional Council, with Australian Government support, invested $10.5m in upgrading its passenger terminal in 2017.

"The next priority for the airport is a larger apron, and … a new, longer runway, which would have included a ground-based ILS. The adoption of satellite-based APV, instead of legacy ILS technology, would provide a 5 percent saving on the runway project cost and provide superior longevity and availability" Mr. Perram said.

For regional airports, SBAS will extend existing APV capability to charter, business jet, rescue and aeromedical aircraft, bringing a new level of safety to these operations. Additionally, at expanding airports such as Armidale, millions of

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[100] Case study provided by John Barnden and Phillip Perram, Armidale Regional Council by email from Andrew Andersen. 13 February 2019.

dollars can could be saved through Localiser Performance with Vertical Guidance (LPV) flight procedures, which use SBAS to support landings in weather conditions that are currently only possible with costly ILS ground-based infrastructure.

"Safer and more reliable operations in poor weather won't just benefit airlines and the airport. SBAS will serve a role in our airport's contribution to a modern, connected city and region, to support sustainable growth and better meet the needs of our community", Mr Perram noted.

9.7 Summary

Table A12 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning. The total quantitative benefits of SBAS signals to the aviation sector is **PV $404m** over 30 years.

Table AV12 – Benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Reduced risk of CFIT	Metre, integrity	Various on-board collision avoidance systems and landing guidance systems	$246m and 146 fatalities and 92 injuries avoided. $38m in avoided capital replacement costs for lost aircraft	L1, DFMC
Increased network reliability and the reduction of operating and passenger costs associated with DDC	Metre, integrity	ILS (where available) that allows for landing in lower cloud at 20 civilian airports	$68m as a result of reduced aircraft operating time, passenger time savings, and alternative transport methods	L1, DFMC
Increase in successfully completed rescue and medical flights, leading to reduced morbidity and mortality	Metre, integrity	Alternative guidance systems (e.g. RNP)	$52m due to increased quality of life resulting from faster medical treatment	L1, DFMC
SBAS as a backup system for ILS equipped airports	Metre, integrity	No current backup technology available at these airports	SBAS signals to act as a backup for ILS in case of ILS blackouts allowing for continued airport operations	L1, DFMC
Increasing capacity and throughput at regional airports	Metre, integrity	ILS where available, but at high cost	SBAS signals can provide a viable and affordable alternative to ILS	L1, DFMC

A range of additional applications in the aviation sector have been identified throughout this research but have not been quantified (or described qualitatively) for a range of reasons[101]. A collection of these applications is provided in Chapter 18 on additional applications.

9.8 Assumptions and limitations

The economic modelling undertaken for this sector has been based on a combination of official data sources, desktop research, information provided by the Demonstrator Projects as well as rational and logical assumptions. These assumptions have all been agreed in discussion with the relevant Demonstrator Project and FrontierSI.

In addition to standard caveats around economic modelling, the following assumptions and limitations are worth highlighting:

Present value discount

All quantitative benefits have been discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

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[101] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

SBAS signal improvement in diversions, delays and cancellations

Wherever possible real operational data were relied upon to calibrate the potential benefits to aviation. Where possible, these estimates have been conservatively adjusted to represent the entire regional aviation sector using publicly available data. Due to incomplete participation from the commercial aviation sector, there may be underestimates in direct benefits to passenger and airlines from DDCs.

Air-traffic growth rate

Air traffic is assumed to grow at 1.7 percent per annum indefinitely for the purposes of this analysis. This was agreed with representatives from Airways New Zealand and Airservices Australia.

Air-ambulance growth rate

New Zealand air ambulance capacity is estimated to grow at six percent from 2017 to 2020 (the first year of analysis), and then plateau, following population trends. The six percent assumption is based on historical trends, but Australia followed a similar trend until levelling off approximately seven years ago.

Australian air ambulance capacity is estimated to grow with population. Australian population statistics are based on the Australian Bureau of Statistics, medium projection.

Avoided disability from increases in successfully completed rescue and medical flights

As noted in the text of the main document, the avoided disability from increases in successful air ambulance and transport flights should be treated with caution. The underlying transport estimates are based on several assumptions. Potential improvements in medical outcomes are based on one highly stylised example. Actual medical data were not available for the purposes of this project.

Construction sector

Key findings

Globally, the construction sector is an important contributor to all economies. In Australia and New Zealand, GDP contribution is estimated at 14 percent and eight percent respectively. The sector includes a broad range of operators, from advanced large-scale operations to smaller operations that still primarily rely on manual labour.

Highlights

Total benefits of **PV AUD$1.20b** are anticipated in the construction sector from the deployment of the SBAS signals – L1, DFMC, and PPP – over a 30-year period. A selection of these benefits consists of:

- A total of **2,023 vehicle collision incidents** (fatalities and serious injuries) avoided due to a collison avoidance system (CAS) enabled by SBAS signals will result in avoided indirect costs of **PV$770m** worth of operating expenditure savings over a 30-year period.
- **1,700 falls from height (FFH) serious injuries** avoided due to the use of enhanced geo-fencing in the heavy and civil engineering sub-sector resulting in **PV$224m** worth of savings over a 30-year period.
- **2,000 serious injuries** avoided in vehicle collisions due to the use of an effective CAS enabled by the SBAS signals. This will result in **PV$191m** in avoided costs to the wider economy over a 30-year period.
- **23 fatalities** avoided in vehicle collisions due to the use of an effective CAS enabled by the SBAS signals. This will result in **PV$20m** in avoided costs to the wider economy over a 30-year period.
- **7 FFH fatalities** avoided due to the use of enhanced geo-fencing in the heavy and civil engineering sub-sector resulting in **PV$9m** worth of savings over a 30-year period.

Quantifiable benefits

Figure CO4 – Benefits by category (30-year, AUD)

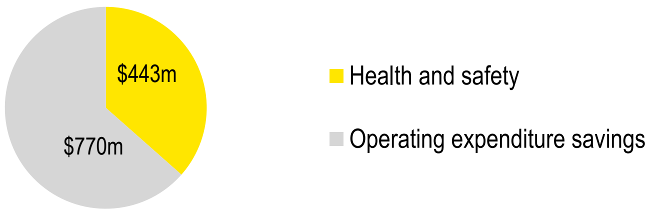


Figure CO5 – Benefits by geography (30-year, AUD)

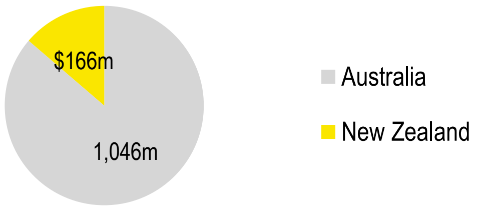
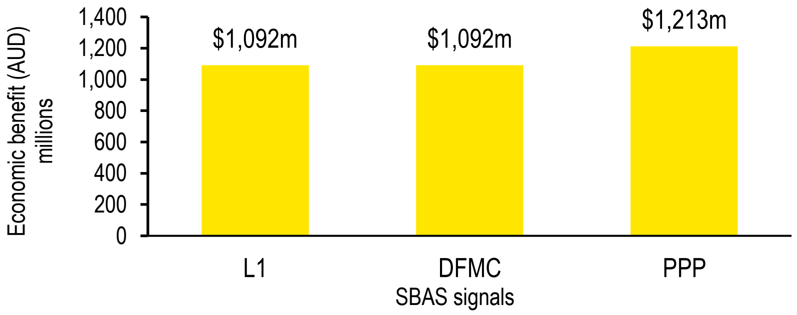


Figure CO6 – Benefits by signal type (30-year, AUD)



10. Construction sector

10.1 Sector description

The construction sector involves a range of activities including the design and build of major infrastructure such as buildings, roads, rail, and bridges[102]. The construction sector contributes significantly to GDP and labour market opportunities across Australia and New Zealand. The Australian construction sector grew to $247b in 2017, accounting for 14 percent of Australian GDP, whilst employing over 1.11 million Australians[103]. The New Zealand construction sector contributed eight percent of the GDP in 2016[104,105] and as of 2018, employs 169,300 New Zealanders –a 15 percent increase from 2016[106].

In general, the findings in this Chapter apply to the construction sector as a whole. However, various sub-sectors of the construction sector have been the focus of different pieces of analysis. For example, the benefits associated with reduced falls from heights (FFH) are estimated to only accrue to the heavy and civil engineering sub-sector. These demarcations within the construction sector are described when appropriate.

10.2 Use of positioning technology

The construction industry has typically been an early adopter of precise positioning or standalone GNSS. These are often used in applications that are fundamental to support concept, design, and construction of infrastructure projects. For example, it facilitates efficient flow of data across surveying of sites through more accurate positioning information of assets on GIS, thereby maximising efficiency of operations[107].

The specific accuracy of positioning required for construction varies depending on the application and activity. These requirements are often defined on a case-by-case basis, as there are currently no universally adopted and defined standards for positioning requirements. Established (and emerging) positioning technologies within the sector are reportedly able to achieve up to centimetre level accuracy using systems such as RTK. However, investment in the capable receivers and services is required before this level of performance is accessible[107].

Discussions with the sector have highlighted the value of precise positioning for a variety of projects, particularly in remote locations or dense urban areas in Australia. For example, in remote areas the lack of reliable terrestrial communications means there is poor access to mobile internet or expensive alternatives (e.g. subscription to RTK). There remains a gap for a reliable and economical positioning solution to aid with the $42b worth of current construction activity across Australia[108]. The same message can be echoed for New Zealand, in which the annual value of construction is forecast to rise from $6.5b in 2016 to a peak at $7.9b in 2019[109].

10.3 Demonstrator Project descriptions

A Demonstrator Project was commissioned to investigate the potential benefits of the SBAS signals to the construction sector as described in Table CO1. The Position Partners/University of NSW (UNSW) Demonstrator Project investigated the use of the three SBAS signals to ascertain the health and safety and site efficiency benefits at construction sites across Australia. Additional discussions with the sector were conducted to ascertain the

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[102] For the purposes of this Chapter all construction activities described are above ground activities only.
[103] Australian Construction Industry Forum (2018) Construction industry forecast update November 2018. Retrieved from: https://www.acif.com.au/subscribe/type/acmr-only-nov-18
[104] StatsNZ. (2019) National accounts – GDP, nominal, actual, ANZSIC06 Industry groups- table reference RNA001AA. Retrieved from: http://archive.stats.govt.nz/infoshare/
[105] PwC (2016) Valuing the role of construction in the New Zealand economy. Retrieved from: https://www.pwc.co.nz/pdfs/CSG-PwC-Value-of-Construction-Sector-NZ.pdf
[106] Stats NZ (2018) Business demography statistics enterprises by industry 2000–18. Retrieved from: http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE7604&_ga=2.18907836.526817415.1548124032-1510139112.1524443312#
[107] Acil Allen (2013) Precise positioning in the construction sector. Retrieved from: http://www.ignss.org/LinkClick.aspx?fileticket=ntyClJz4fh8%3D&tabid=56
[108] Australian Construction Industry Forum (2018) Two up and two down – trends forecast the Australian Construction Market Report. Retrieved from: https://www.acif.com.au/forecasts/summary
[109] Ministry of Business, Innovation and Employment (2017) Future demand for construction workers. Retrieved from: https://www.mbie.govt.nz/dmsdocument/46-future-demand-for-construction-workers-2017-pdf

benefits to the wider construction sector in Australia along with the New Zealand market.

Table CO1 – Construction sector project description

Demonstrator project	Description	Signals tested
Position Partners/UNSW	Investigating the use of SBAS signals for fit-for-purpose, high-accuracy positioning to improve health and safety outcomes and site efficiencies for Australian and New Zealand construction industries.	L1, DFMC, PPP

10.4 Anticipated benefits

A benefits mapping exercise was undertaken with the Demonstrator Project to identify how the benefits of the SBAS signals could flow through to operating changes in the future. This then led to the identification of the following potential operational benefits:

Reduction in falls from height fatalities

The SBAS signals are anticipated to play a role in accelerating the uptake and potential applications of geo-fencing in activities within the heavy and civil engineering sub-sector. Geo-fencing enables dynamic, real-time demarcation of safe working perimeters around site hazards, such as pile holes, trenches, or excavation sites, thereby reducing the risk of FFH fatalities.

It is anticipated that the accuracy and integrity afforded by the signals will enable geo-fencing to move from concept to economic reality.

Reduction in falls from height serious injuries

In addition to the reduction in FFH fatalities benefit, the SBAS signals are anticipated to play a role in geo-fencing preventing FFH causing serious injuries to workers.

Reduction in vehicle collision fatalities

Construction sites are often dynamic environments, involving the movement of large vehicles through worksites containing workers and other obstacles/hazards. Additionally, drivers are often subject to blind spots given the size of the vehicles. It is therefore expected that vehicle incidents serve as one of the largest contributors of fatalities within the sector.

It is anticipated that greater accuracy and spatial resolution afforded by the SBAS signals will allow for a reduction in the size of collision avoidance buffer zones in vehicles, thereby reducing the risk of false positives. This can allow for greater confidence in the vehicle's collision avoidance system (CAS), resulting in reduced fatalities due to vehicle collisions.

Reduction in vehicle collision serious injuries

In addition to the reduction in vehicle collision fatalities benefit, the SBAS signals are anticipated to assist in reducing serious injuries due to vehicle collisions by improving the effectiveness and trustworthiness of vehicle CAS.

Reduction in indirect costs due to vehicle collision incidents

The SBAS signals in CAS are anticipated to play a role in reducing the indirect costs that arise from vehicle collision incidents, including vehicle damage and operational downtime.

Site surveying efficiencies

It is anticipated that the SBAS signals will increase the use and capability of UAVs for operations such as surveying, tracking personnel and equipment, and undertaking site audit activities. Use of the SBAS signals is anticipated to improve site productivities and prevent employees from needing to conduct survey activities from heights in certain instances.

These anticipated benefits have been classified into the following benefit categories, as shown in Table CO2.

Table CO2 – Construction sector benefit categorisation[110]

Benefit	Benefit category	Quantitative?
Reduction in falls from height fatalities	Health and safety	Yes
Reduction in falls from height serious injuries	Health and safety	Yes
Reduction in vehicle collision fatalities	Health and safety	Yes
Reduction in vehicle collision serious injuries	Health and safety	Yes
Reduction in indirect costs due to vehicle collision incidents	Operating expenditure savings	Yes
Site surveying efficiencies	Operating expenditure savings	No

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[110] Colour coding in Table CO2 has been used to more clearly highlight the relevant benefit categories.

10.5 Positioning needs and current methods

There are no regulatory requirements when it comes to positioning in the construction sector as these vary depending on the application and environment. Discussions with the sector reinforced that positioning accuracy requirements differ for each benefit and can be driven by application needs, the manufacturers of equipment, and individual construction companies. The purpose of this section is to detail these positioning needs (and current methods) to the extent possible.

10.5.1 Reduction in falls from height fatalities and serious injuries

Current health and safety standards require safety provisions such as physical barriers, handrails, and harnesses to prevent FFH when working at heights of two metres or more[111]. Despite these mandated provisions, FFH remain a leading cause of serious injuries and fatalities in the sector.

Discussions with sector experts suggest that FFH incidents within the commercial and residential construction sub-sector mainly occur due to non-compliance with required health and safety standards. In contrast, these standards are often not applicable within the heavy and civil engineering sub-sector as expansive and highly dynamic environments are an inevitable part of their work site. As a result, the barriers are subject to constant movement around the site[112].

Construction activity in the heavy and civil engineering sub-sector includes network infrastructure such as telecommunications, water, electricity transmission and distribution, and transportation.

Following sector discussions, it was agreed that geo-fencing in the heavy and civil engineering sub-sector is operationally and commercially feasible for reducing FFH incidents. This is dependent on the SBAS signals achieving sub-metre (L1 and DFMC) to 10 centimetre (PPP) horizontal accuracy[113]. FFH incidents in this Chapter therefore focus on falls above the surface and site hazards such as pile holes, trenches, or excavation sites[114].

Geo-fencing based on telematics and satellite positioning is a relatively new application[115]. It is a virtual perimeter for a real-world geographic area that can be used to designate safe areas for workers to operate without the risk of FFH[116]. The perimeter can be dynamically generated as a radius around a point location or through a predefined set of boundaries[117]. The coordinates of these boundaries are registered to a portable device which a site manager can use to see and manage the geo-fence[118].

Based on discussions with the sector, it is understood an alert system akin to CAS would be utilised. Construction workers would carry alert devices mounted on their protective gear that would activate when at risk of breaching a geo-fence. The geo-fencing could then be updated throughout the project lifecycle to reflect the dynamic nature of the work site, making it more reliable than existing physical interventions. The positioning performance of the geo-fence relies on the robustness, precision, and accuracy of the

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[111] Safe Work Australia (n.d.) Managing the risk of falls at workplaces. Retrieved from: safeworkaustralia.gov.au/system/files/documents/1810/model-cop-managing-the-risk-of-falls-at-workplaces.pdf; WorkSafe New Zealand (1995) For the provision of facilities and general safety in the construction industry. Retrieved from: worksafe.govt.nz/dmsdocument/545-guidelines-for-the-provision-of-facilities-and-general-safety-in-the-construction-industry

[112] Entwine (2018) Creating value through procurement: a report into public sector procurement of major infrastructure projects. Retrieved from: https://infrastructure.org.nz/resources/Documents/Reports/Infrastructure%20NZ%20Procurement%20Study%20Report%20FINAL.pdf

[113] Acil Allen (2013) Precise positioning services in the construction sector. Retrieved from: http://www.ignss.org/LinkClick.aspx?fileticket=ntyClJz4fh8%3D&tabid=56

[114] Safe Work Australia (2018) Priority industry snapshot: construction. Retrieved from: www.safeworkaustralia.gov.au/system/files/documents/1807/construction-priority-industry-snapshot-2018.pdf; and WorkSafe New Zealand (2015) Construction in New Zealand. Retrieved from: www.sitesafe.org.nz/globalassets/guides-and-resources/nz-health-and-safety-reform/worksafe-construction-safety-survey-handout.pdf

[115] Reclus, F. (n.d.) Geofencing for fleet & freight management. Paper presented at 2009 9th International Conference on Intelligent Transport Systems Telecommunications, Lille, France. Retrieved from: https://ieeexplore.ieee.org/abstract/document/5399328

[116] Reclus, F. (2013) Geofencing. In Nait-Sidi-Moh, A.and Bakhouya, M. (Eds.), Geopositioning and mobility. John Wiley & Sons doi:10.1002/9781118743751.ch6

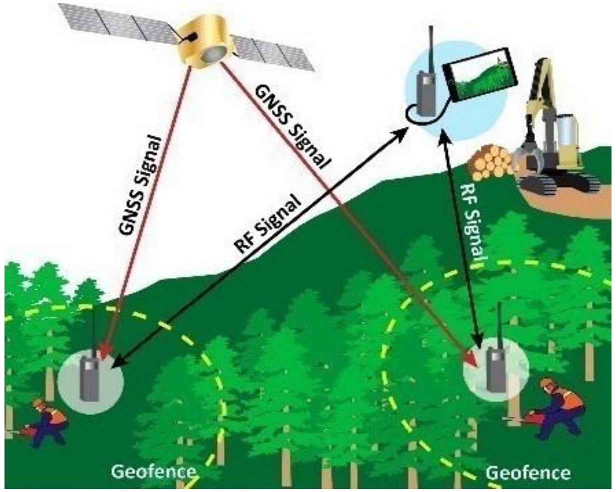
[117] French, J. (2018) Two ways geofencing makes construction sites safer. Retrieved from: https://www.teletracnavman.co.nz/blog/two-ways-geofencing-makes-construction-sites-safer

[118] Data obtained from UNSW: Zimbelman, E. G., Keefe, R. F., Strand, E. K., Kolden, C. A., and Wempe, A. M. (2017) Hazards in motion: development of mobile geofences for use in logging safety. Sensors, 17(4), 822. Chicago. Retrieved from: https://www.mdpi.com/1424-8220/17/4/822

positioning system, which can be standalone GNSS-based or wireless (e.g. Bluetooth, Wi-Fi, and radio frequency identification (RFID))[118].

Currently there are no defined standards around positioning accuracy for geo-fencing in the sector. In the forestry sector, geo-fences are used to reduce accidents in logging operations by using GNSS, and radio-frequency (RF) to meet positioning requirements on the wearable devices, which register the geo-fence with respect to the employee (Figure CO4)[118]. The GNSS receivers can vary in price and accuracy, with costs increasing proportional to the accuracy. These are consumer grade (5–10 metres), mid-range grade (2–5 metres), and professional grade (2–5 centimetres, when augmented by a system such as RTK)[118].

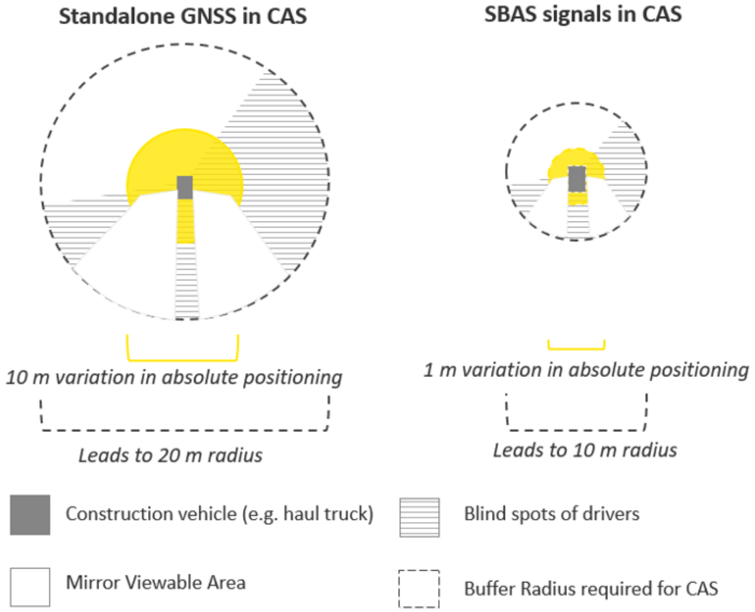
Figure CO4 – Geo-fencing in the forestry sub-sector used in conjunction with RF-enabled devices to reduce fatal and non-fatal accidents



10.5.2 Reduction in vehicle collision fatalities, serious injuries, and indirect costs

Operators of heavy machinery and equipment as well as vehicles often deal with significant blind spots and limited manoeuvrability on construction sites – collectively these are amplified by the vehicle's scale and configuration. As a result, the risk of collisions with other structures, vehicles, or workers is substantial, as shown in Figure CO5[119].

Figure CO5 – Buffer implication from absolute positioning variations and blind-area implications at ground plane. Note diagram is not to scale.[119]



CAS are built-into a vehicle's safety system and can be interfaced into the display unit of a vehicle, or as a stand-alone component to add to the vehicle's dashboard such as a LED display screen[119,120]. Additional to detecting obstructive objects on-site at real-time, workers also wear tag-based systems (such as RFID) on their clothing which are registered to the vehicle's CAS system[119,120].

The CAS generates a radius or buffer zone around each vehicle based on the vehicle size and time to collision (Figure CO5)[119]. When this buffer zone overlaps with another vehicle's buffer zone, or an object or worker comes within the buffer zone, the system alerts the driver to a potential hazard through an audible alarm. CAS positioning requirements differ significantly

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[119] LeddarTech (n.d.) Collision avoidance solutions for industrial vehicles and heavy equipment using Leddar technology. Retrieved from: https://leddartech.com/app/uploads/dlm_uploads/2016/04/Solution-Overview-Leddar-for-industrial-vehicles-and-heavy-equipment-1.pdf

[120] Strata Worldwide (n.d.) Proximity detection & collision Avoidance. Retrieved from: https://www.strataworldwide.com/download-file/1916

across regulatory bodies and equipment manufacturers. Although some similarities exist between vehicles used in the resources sector and the construction sector, where necessary, proxies have been drawn from Minetec's resource sector report to describe similar requirements faced by the construction sector[121]. For a more detailed description please refer to the resource Chapter.

The SBAS signals' enhanced spatial accuracy is anticipated to benefit the proximity detection system (PDS) component of a vehicle's CAS. A PDS is a sensor-based CAS that can detect vehicles, objects, and people within the vicinity of the vehicle and register the event. PDS is an active method of spatial monitoring. Currently PDS is used exclusively for detection and alerts and does not always initiate a response. The PDS is responsible for hazard detection but operators of machinery, equipment or vehicles are required to take action to prevent collisions. Consequently, the PDS component stands to benefit as combining the sensor-based technology with more accurate positioning through the SBAS signals will result in an enhanced and potentially more effective CAS[122].

According to empirical research, the minimum time required by a driver to appropriately react and avoid a hazard is 700 metres[123]. Information provided through consultation with sector experts indicates that a buffer radius no greater than 10 metres is required to accommodate this reaction time. A CAS radius greater than 10 metres would increase the likelihood of false positives as a larger buffer zone of 20 metres would be required to alert the driver to collisions. This would reduce the system's integrity and potentially decrease users' trust in its capability to the extent that the user disables the system[121]. This example is cited in more detail in the resource Chapter.

Should the CAS system achieve a one metre variation in positioning (Table CO3, Figure CO5), it would ensure a high level of safety as a 10-metre radius is more likely to meet the needs of users. By allowing operators to react within 700 metres, it significantly reduces the incidence of false positives simultaneously overcoming the blind spots operators/drivers experience with large vehicles. Enhancing the integrity of the CAS equates to increased usage and uptake. Moreover, the higher accuracy offered by the SBAS signals enables clearer identification of nearby vehicles and objects located in blind spots. This enables a CAS to adjust the urgency of its alert more accurately and effectively aids in avoiding collisions.

10.6 Sector benefits

The following sections detail the benefits of SBAS relative to the status quo, describe the anticipated economic impact, and estimate how benefits are attributed across the three signals.

10.6.1 Signal attribution

Benefits in relation to the use of the SBAS signals in geo-fencing, CAS and UAVs are expected to accrue fully towards PPP given its ability to achieve sub-metre down to 10 centimetres. It is also expected to accrue evenly across L1 and DFMC, but not at full attribution, given the signals' ability to provide only up to sub-metre accuracy.

Table CO3 gives more information on the benefits and their signal attribution and test results. These indicative test results have been provided by FrontierSI as representative results of the testing carried out by the SBAS Demonstrator Project in this sector. Where deviations exist, DFMC SBAS results are expected to be similar to SBAS L1 in an operational system. The testing was carried out in partial to moderate obstructed environments with mid-range equipment. Values are presented at a 95 percent confidence interval.

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[121] Minetec (n.d.) Proximity detection + collision avoidance systems for dummies. Retrieved from: minetec.com.au/news/proximity-detection-collision-avoidance-systems-for-dummies/

[122] Strata Worldwide (n.d.) Proximity detection & collision avoidance. Retrieved from: https://www.strataworldwide.com/download-file/1916

[123] Yang, B et al. (2017) Influences of waiting time on driver behaviours while implementing in-vehicle traffic light for priority-controlled unsignalized intersections. Journal of Advanced Transportation. Retrieved from: http://downloads.hindawi.com/journals/jat/2017/7871561.pdf?bcsi_scan_01d939382f6c0b14=1

Table CO3 – Construction sector signal attribution

Signal	Construction sector test results	
	Expected horizontal performance (m)	Expected vertical performance (m)
SBAS L1	1.1	2.2
SBAS DFMC	1.8	2.3
PPP	0.7	1.2

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Quantitative benefits					
Reduction in falls from height fatalities	Sub-metre	90%	90%	100%	PPP offers an incremental accuracy benefit over L1 and DFMC
Reduction in falls from height serious injuries	Sub-metre	90%	90%	100%	PPP offers an incremental accuracy benefit over L1 and DFMC
Reduction in vehicle collision serious injuries	Sub-metre	90%	90%	100%	PPP offers an incremental accuracy benefit over L1 and DFMC
Reduction in vehicle collision fatalities	Sub-metre	90%	90%	100%	PPP offers an incremental accuracy benefit over L1 and DFMC
Reduction in indirect costs due to vehicle collision incidents	Sub-metre	90%	90%	100%	PPP offers an incremental accuracy benefit over L1 and DFMC
Qualitative benefits					
Site surveying efficiencies	Sub-metre to decimetre	✓	✓	✓	PPP offers the incremental benefit of sub-metre to 10cm positioning

10.6.2 Uptake rate

A linear uptake curve has been used to illustrate the benefits associated with a reduction in FFH incidents through geo-fencing. This decision reflects discussions with the sector regarding an expectation of consistent mandatory uptake within the first five years of an operational SBAS, then a plateau at full uptake for the next 25 years. The primary basis for this view offered by the sector is that the construction sector is a large contributor to total job-related fatalities and serious injuries, and as such, significant effort has been made to achieve zero-harm environments. To that end, any application which assists the sector in achieving this objective is likely to receive strong uptake and adopted into existing health and safety regulations.

An S-curve reflecting uptake has been used to illustrate the benefits associated with reduction in vehicle collisions through enhanced CAS and the benefit realised through reduction in indirect costs. This decision reflects discussion with the sector which suggests a slow initial uptake as the sector will want to see proof that it works, followed by exponential uptake as most of the sector follows suit as they come to realise the benefits of SBAS-enhanced CAS, and then a steady plateau in the long run.

10.6.3 Quantitative benefits

The economic modelling undertaken for this Chapter is based on a combination of official data sources, desktop research, and information provided by the Demonstrator Project. These assumptions have all been agreed in discussion with the Demonstrator Project and FrontierSI. Economic models are based on a scenario whereby the SBAS signals achieve the required performance criteria and serve as a viable positioning option for the construction sector across Australia and New Zealand.

10.6.3.1 Reduction in falls from height – fatalities

Over a 30-year forecast period, it is anticipated that seven fatalities will be avoided from greater uptake of geo-fencing in the heavy and civil engineering construction sub-sector. This will be directly attributable to the implementation of the SBAS signals in geo-fencing, resulting in an economic saving of PV$9m.

In arriving at this figure, statistical data was relied upon to gauge the proportion of FFH fatalities as a function of the total heavy and civil engineering sub-sector. Safe Work Australia reported that from the total of 3.3 fatalities per 100,000 workers in the construction sector, 13 percent are due to FFH, of which 14 percent of FFH fatalities are attributable to the heavy and civil engineering sub-sector[124]. WorkSafe New Zealand reported that an average of five workers died annually between 2011 and 2018 in the construction industry[125]. From this data, 18 percent were due to FFH, of which 21 percent was attributable to the heavy and civil engineering sub-sector[124]. These values were held constant each year throughout the 30-year forecast period.

Another key challenge in quantifying this benefit has been identification of the likely effectiveness of geo-fencing at avoiding FFH fatalities. Given that this technology is emerging within the sector, empirical research from an analogous application was leveraged as a proxy, providing a reduction factor of 50 percent[126].

Specifically, the proxy was obtained through a study conducted to analyse geo-fencing effectiveness in preventing accidents for application in the forestry sector[126]. This study examined the use of standalone GNSS and a Radio-Frequency enabled GNSS (GNSS-RF). Three GNSS receiver grades were tested: professional, mid-range, and consumer. The study concluded that the GNSS errors greatly influenced the effectiveness of geo-fencing. GNSS error rates would be improved significantly if two main changes were made:

- Implementation of real-time correction methods improving positioning accuracy
- Using higher quality GNSS-RF transponders.

Demonstrator Project data suggests that the SBAS signals have the capability to provide the same service as mid-range grade or even professional grade GNSS receivers at the price of a consumer grade, whilst offering signal integrity, accuracy, and robustness. Significantly, SBAS signals will play a key role in achieving positioning accuracy, resulting in geo-fencing effectiveness improvement by a ratio of 50 percent, with the remaining 50 percent attributable to a higher quality communications method such as radio frequency.

The anticipated total number of avoided fatalities due to an effective geo-fence enabled by SBAS were multiplied by a value of life figure, adjusted for uptake, and discounted to present values to arrive at the final economic saving shown in Table C04.

Table C04 – Reduction in fatalities due to fall from heights (30-year calculation)

Factor	Value	Notes
Total number of employees in the construction sector	61m	Total number of employees in the 30-year forecast period
Total number of fatalities in the construction sector	2,040	Total number of fatalities in the forecast period
Total number of FFH fatalities in the construction sector	285	13% of fatalities due to FFH in Australia (209 fatalities) 18% of fatalities due to FFH in New Zealand (76 fatalities)
Total number of FFH fatalities in the heavy and civil engineering construction sub-sector	45	14% FFH fatalities in Australian sub-sector 21% FFH fatalities in New Zealand sub-sector
FFH fatalities avoided by geo-fencing	23	Assumed at 50%
FFH fatalities avoided due to SBAS	8	Assumed three systems in a geo-fence: positioning, behaviour, and data-transfer
FFH fatalities avoided due to SBAS adjusted for uptake	7	Linear uptake for first four years with full uptake in year five.
Value of FFH fatalities avoided	$25m	Based on statistical value of life figure of $3.45m
Present value of FFH fatalities avoided	$9m	Discounted at 6.5%

Note: totals may not sum due to rounding

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[124] Safe Work Australia. (2018). Priority industry snapshot: construction. Retrieved from: www.safeworkaustralia.gov.au/system/files/documents/1807/construction-priority-industry-snapshot-2018.pdf; and WorkSafe New Zealand. (2015). Construction in New Zealand. Retrieved from: www.sitesafe.org.nz/globalassets/guides-and-resources/nz-health-and-safety-reform/worksafe-construction-safety-survey-handout.pdf

[125] WorkSafe New Zealand (2019) Workplace fatalities by focus area. Retrieved from: https://worksafe.govt.nz/data-and-research/ws-data/fatalities/by-focus-area/

[126] Data obtained from UNSW: Zimbelman, E. G., Keefe, R. F., Strand, E. K., Kolden, C. A., & Wempe, A. M. (2017) Hazards in motion: development of mobile geofences for use in logging safety. Sensors, 17(4), 822. Chicago. Retrieved from: https://www.mdpi.com/1424-8220/17/4/822

10.6.3.2 Reduction in falls from height - serious injuries

Over a 30-year forecast period, it is anticipated that 1,700 serious injuries will be avoided from greater uptake of geo-fencing in the heavy and civil engineering sub-sector. These are directly attributable to the implementation of the SBAS signals, resulting in anticipated economic savings of PV$224m.

This calculation follows the same methodology as that for the reduction in the FFH fatalities benefit category but has two main replacement values, as follows.

First, this economic savings accounts for the total projected FFH construction serious injuries in Australia and New Zealand for the 30-year period as derived from government statistical data[127]. Safe Work Australia reported that between 2006 and 2016, construction sector serious injuries decreased at a rate of 0.23 percent per year. From this 12 percent of serious injuries were due to FFH, of which 14 percent were attributable to the heavy and civil engineering sub-sector[127]. WorkSafe New Zealand reported that between 2009 and 2017, the rate of serious injuries was two percent per year. From this, nine percent of serious injuries were due to FFH, of which 21 percent were attributable to heavy and civil engineering[127]. These values were held constant each year throughout the 30-year forecast period.

Second, this model utilises a standardised economic cost of serious injuries valuation which assumes that the injury would have wider economic costs aside from the costs borne by the employer and compensation schemes, such as costs of hospitals and doctors and thus the cost to the wider economy.

The resulting number of avoided serious injuries due to an effective SBAS-enabled geo-fence was then multiplied by the cost of serious injuries, adjusted for uptake and discounted to present values to arrive at a final economic saving shown in Table CO5.

Table CO5 – Reduction in serious injuries due to FFH (30-year calculation)

Factor	Value	Notes
Total number of serious injuries in the construction sector	594,000	Total number of serious injuries in the Australian and New Zealand sector over the 30-year period.
Total number FFH serious injuries	65,750	12% of Australia's total serious injuries due to FFH 9% of New Zealand's total serious injuries due to FFH.
Total number of FFH serious claims in the heavy and civil engineering construction sub-sector	10,630	Of total FFH serious injuries, 14% FFH Australian serious injuries attributable to sub-sector 21% FFH New Zealand serious injuries attributable to sub-sector
FFH serious injuries avoided by geo-fencing	5,320	Assumed at 50%
FFH serious injuries avoided due to SBAS	1,780	Assumed three systems in a geo-fence: positioning, behaviour, and data-transfer
FFH serious injuries avoided due to SBAS adjusted for uptake	1,670	Linear uptake for first four years with full uptake in year five.
Value of FFH serious injuries avoided	$573m	Based on value of serious injury of $344,000
Present value of FFH serious injuries avoided	$224m	Discounted at 6.5%

Note: totals may not sum due to rounding

10.6.3.3 Reduction in vehicle collision – fatalities

It is anticipated that a total of 23 fatalities will be avoided through the implementation of an effective PDS technology in the CAS of heavy construction and civil engineering vehicles over a 30-year assessment period. This is directly attributable to the use of SBAS signals, resulting in an economic savings of PV$20m.

This figure accounts for total projected vehicle-related fatalities over a 30-year period, derived from statistics for the Australian and New Zealand

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[127] Safe Work Australia (2018) Priority industry snapshot: construction. Retrieved from: www.safeworkaustralia.gov.au/system/files/documents/1807/construction-priority-industry-snapshot-2018.pdf; and WorkSafe New Zealand (2015) Construction in New Zealand. Retrieved from: www.sitesafe.org.nz/globalassets/guides-and-resources/nz-health-and-safety-reform/worksafe-construction-safety-survey-handout.pdf

construction sector including all sub-sectors, the number of incidents avoided using an effective CAS, associated costs when an incident occurs, and uptake[128]. According to Safe Work Australia, 16 percent of the total construction sector fatalities were due to vehicle incidents. In New Zealand, 49 percent of the fatalities were due to vehicle incidents[128].

A key challenge in the quantification of the benefit was understanding the impact of CAS on vehicle-related incidents, including fatalities and serious injuries, within the construction industry[129]. An AA study exploring driver inattention and distraction in the role of serious casualty crashes within Australia concluded 16.1 percent of vehicle incidents over the 30-year period would be attributable to driver inattention along with lack of visibility, particularly given the large size of construction vehicles[130].

The reasons attributable to 16.1 percent of driver inattention causing serious crashes were[129]:

- Misprioritised: attention excessively focussed on less safety-critical aspects of driving
- Neglected: driver fails to attend to activities critical for safe driving
- Cursory: driver superficially attends to activities critical for safe driving, for example driving despite lack of clear vision or blind spots
- Diverted: driver's attention is diverted to an activity that is not critical for safe driving.

Modelling assumed that vehicle incidents caused by various forms of driver inattention stand to benefit from an effective CAS.

It should be noted that a reduction in fatalities could not be exclusively attributed to increased uptake of CAS in vehicles. This aligns with vehicle incidents that occur in the resource sector[129]. Better utilisation of CAS is also influenced by user behaviour, that is, increased trust in system capability to warn the user and prevent potential collisions. This is also applicable for reducing serious injuries.

The proportion of positioning within the components that make up a CAS was also considered and used to find the proportion of fatalities avoided that was directly attributable to the SBAS signals. This was determined to be 50 percent through discussions with the sector experts.

To determine the value quotient, the anticipated total number of avoided vehicle incidents causing fatalities due to an effective SBAS-enabled CAS was multiplied by a value of life figure. These were adjusted for uptake and discounted to present value to obtain a final economic saving as per Table C06.

Table C06 – Reduction in vehicle collision fatalities (30-year calculation)

Factor	Value	Notes
Total number of employees in the construction industry	61m	Total number of employees in the 30-year forecast period across Australia and New Zealand
Total number of fatalities in the construction industry	2,040	Total number of fatalities in the forecast period
Total number of vehicle collision fatalities	470	In Australia 16% due to vehicle incidents In New Zealand, 49% due to vehicle related accidents
Total fatalities avoided due to enhanced CAS	76	Assumed 16.1% of fatalities are due to avoidable inattention and lack of sight
Total fatalities avoided due to SBAS in a CAS	38	Assumed 50% through discussions with sector experts
Adjusted for uptake	23	S-curve over 30 years
Value of fatalities avoided	$78m	Based on value of life figure of $3.45m
Present value	$20m	Discounted at 6.5%

Note: totals may not sum due to rounding

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[128] Safe Work Australia (2018) Priority industry snapshot: construction. Retrieved from: www.safeworkaustralia.gov.au/system/files/documents/1807/construction-priority-industry-snapshot-2018.pdf; and WorkSafe New Zealand (2015) Construction in New Zealand. Retrieved from: www.sitesafe.org.nz/globalassets/guides-and-resources/nz-health-and-safety-reform/worksafe-construction-safety-survey-handout.pdf

[129] This approach was also utilised in the resource sector. For a more detailed description of this study please see the resources Chapter.

[130] Beanland, V., Fitzharris, M., Young, KL. and Lenne, MG. (2013) Driver inattention and driver distraction in serious casualty crashes: data from the Australian National Crash In-depth Study. Retrieved from: https://www.ncbi.nlm.nih.gov/pubmed/23499981/

10.6.3.4 Reduction in vehicle collision - serious injuries

It is anticipated that a total of 2,000 serious injuries will be avoided through the implementation of an effective PDS technology in the CAS of heavy construction and civil engineering vehicles over a 30-year assessment period. This is directly attributable to the use of SBAS signals, resulting in economic savings of PV$191 million.

This calculation follows the same methodology as that for the reduction in vehicle collision fatalities benefit category, but has two main replacement values.

First, this figure accounts for total projected vehicle-related claims for serious injuries over 30 years, derived from statistics for the Australian and New Zealand construction sector including all sub-sectors, the number of incidents avoided using an effective CAS, and uptake. In Australia, of the total serious injuries, 12.7 percent were due to vehicle collisions. In New Zealand, 1.4 percent of serious injuries were due to vehicle collisions[131].

Second, this model utilises a standardised economic cost of serious injuries valuation which is based on the assumption that the injury would have wider economic costs aside from the costs borne by the employer and compensation schemes, such as costs of hospitals and doctors and thus the cost to the wider economy.

The proportion of positioning within the components that make up a CAS was also considered and used to find the proportion of fatalities avoided directly attributable to the SBAS signals. This was determined to be 50 percent through discussions with the sector experts.

To determine the value quotient, the anticipated total number of avoided vehicle incidents causing serious injuries enabled by an effective CAS through SBAS was multiplied by the cost of serious injuries. This was then adjusted for uptake and discounted to present values to obtain a final economic saving as per Table CO7.

Table CO7 – Reduction in vehicle collision serious injuries (30-year calculation)

Factor	Value	Notes
Total number of serious injuries in the construction industry	594,000	Number of serious injury claims in the industry over the 30-year period
Total number of serious injuries due to vehicle related incidents	49,800	12.7% of serious injuries due to vehicle collisions in Australia 1.4% of serious injuries due to vehicle collisions in New Zealand
Total vehicle collision serious injuries avoided due to enhanced CAS	8,023	Assumed 16.1% of serious claims are due to avoidable inattention and lack of sight
Vehicle collision serious claims avoided due to SBAS	4,011	Assumed 50% through discussions with sector experts
Adjusted for uptake	2,000	S-curve over 30 years
Value of serious claims avoided	$687m	Based on value of serious injury of $344,000
Present value	$191m	Discounted at 6.5%

Note: totals may not sum due to rounding

10.6.3.5 Reduction in indirect costs due to vehicle collision incidents

Through discussions with the sector, the benefit associated with indirect costs of vehicle collision incidents was anticipated to increase (i.e. collisions were anticipated to reduce) through the utilisation of an enhanced CAS using the SBAS signals. This benefit encapsulates the indirect costs of both serious injuries and fatality incidents, such as damage and repairs required for the vehicle and site downtime.

Over a 30-year assessment period, it is anticipated that a total of 2,023 incidents will be avoided through an effective PDS in the CAS of heavy and

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[131] Safe Work Australia (2018) Priority industry snapshot: construction. Retrieved from: www.safeworkaustralia.gov.au/system/files/documents/1807/construction-priority-industry-snapshot-2018.pdf; and WorkSafe New Zealand (2015) Construction in New Zealand. Retrieved from: www.sitesafe.org.nz/globalassets/guides-and-resources/nz-health-and-safety-reform/worksafe-construction-safety-survey-handout.pdf

civil engineering construction vehicles. This is directly attributable to the SBAS signals, resulting in an economic saving of PV$770m.

This calculation follows the same methodology as that used for the reduction of vehicle collision fatalities and serious injuries benefit categories but has one main replacement value regarding the indirect costs.

Desktop research indicated that indirect costs (e.g. vehicle damage, site downtime) resulting from an incident on-site ranged from 4 to 20 times the amount of direct costs, such as worker's compensation[132]. The lower bound of this cost range, four percent, was applied to the direct costs to the wider economy as a conservative proxy for indirect costs.

The total number of avoided vehicle incidents due to an effective CAS was then adjusted for uptake and discounted to present values to obtain a final operating expenditure saving as per Table C08.

Table C08 – Reduction in indirect costs from vehicle collision incidents (30-year calculation)

Factor	Value	Notes
Total number of vehicle collision incidents in the construction industry	50,303	Sum of serious injuries and fatality incidents as per Tables C06 and C07
Total number of vehicle collision incidents avoided due to enhanced CAS	8,099	Sum of serious injuries and incidents as per Tables C06 and C07
Total number of vehicle incidents avoided due to SBAS	4,049	Sum of serious injuries and incidents as per Tables C06 and C07
Adjusted for uptake	2,023	S-curve over 30 years and sum of serious injuries and incidents as per Tables C06 and C07
Value of indirect costs avoided	$2.8b	$1.4m of indirect costs per vehicle collision incident
Present value	$770m	Discounted at 6.5%

Note: totals may not sum accordingly with Tables C06 and C07 due to rounding

10.6.4 Qualitative benefits

10.6.4.1 Site surveying efficiencies

A UAV[133,134] is defined as an aircraft that can be flown from a remote location[135]. Although UAVs are in relatively early stages of uptake within the sector, the construction industry is increasingly becoming aware of the range of capabilities offered by UAVs. Some applications include real-time tracking of staff, surveying worksites and providing access to high-definition video/images to publicise progress [136]. The lack of positioning accuracy that currently prevents UAVs from flying within confined spaces, is cited as a detractor to more rapid uptake. As with sector expert opinions on SBAS signal-enabled geo-fencing, rapid uptake can be expected from within the first few years should UAVs be perceived as contributing to achieving zero harm whilst also increasing site productivity[137].

UAVs utilise GNSS receivers which enable users to take images or properly stitch images to create three-dimensional models of chosen locations[138,139]. Conversations with the sector state that the SBAS signals are anticipated to improve the positioning accuracies on-board UAVs. This will enhance UAV

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[132] Sentinal Risk Advisors (2017) The real cost of a workplace accident is five times what you think. Retrieved from: sentinelra.info/blog/real-costs-workplace-accidents-often-hidden

[133] UAVs are also known as drones, remote pilot automated system (RPAS), or unmanned aircraft systems (UAS).

[134] Some similarities exist between the use of UAVs in the construction and spatial sector.

[135] ICAO (n.d.) Remotely piloted aircraft system concept of operations for international IFR operations. Retrieved from https://www.icao.int/safety/ua/documents/rpas%20conops.pdf

[136] Tatum, C. (2017) Unmanned aircraft system applications in construction. Creative Construction Conference 2017. Retrieved from: https://www.sciencedirect.com/science/article/pii/S1877705817330461

[137] PWC (2018) Flying high – drones to drive jobs in construction sector. Retrieved from https://www.pwc.in/assets/pdfs/publications/2018/flying-high.pdf

[138] Position Partners (n.d.) Taking off with RPAS in construction – Position Partners New Zealand. Retrieved from: https://www.positionpartners.co.nz/news/position-partners/taking-off-with-rpas-in-construction/

[139] Siebert, S., and Teizer, J. (2014) Mobile 3D mapping for surveying earthwork projects using an unmanned aerial vehicle (UAV) system. Automation in Construction, 41, 1-14. doi: 10.1016/j.autcon.2014.01.004 Retrieved from: https://www.sciencedirect.com/science/article/pii/S0926580514000193

capability and its contribution to site safety and surveying, and provide site efficiencies leading to an economic productivity benefit.

A case study provided by the Demonstrator Project showed that UAVs were able to take between one to four days to complete a survey of a 61-acre hospital site whilst traditional methods took two to three weeks[140]. UAV surveying allowed the team to assess the site faster with more detail[139]. With the SBAS signals, UAVs will be able to fly into enclosed spaces outdoors, and indoors if there is sky visibility, with accuracies between sub-metre to centimetre reducing the threat of collision with the environment. This allows UAVs to map internal structures that could not normally be created[138].

Discussions with the sector agree that UAVs can be used to conduct surveying, particularly at heights. This can reduce the exposure of employees to working at heights further reducing FFH incidents.

10.7 Summary

Table CO9 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning. The quantifiable economic impact of L1, DFMC and PPP in the construction sector is anticipated to be **PV AUD $1.20b** over 30 years.

Table CO9 – Summary of benefits (30-year, PV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Reduction in falls from height fatalities	Sub-metre	Range of systems to prevent falls, such as perimeter around working areas, guard rails, safety nets and fall arrest systems. Currently geo-fencing can use a combination of standalone GNSS, cellular data, RFID and Wi-Fi	7 fatalities avoided with $9m savings	L1, DFMC, PPP
Reduction in falls from height serious injuries	Sub-metre		1,700 serious injuries avoided with $224m savings	L1, DFMC, PPP
Reduction in vehicle collision fatalities	Sub-metre	Sensor-based and standalone GNSS positioning which can create false positives	23 fatalities avoided with $20m savings	L1, DFMC, PPP
Reduction in vehicle collision serious injuries	Sub-metre		2,000 serious injuries avoided with $191m savings	L1, DFMC, PPP
Reduction in indirect costs due to vehicle collision incidents	Sub-metre		2,023 vehicle collision incidents avoided with $770m savings	L1, DFMC, PPP
Site surveying efficiencies	Sub-metre to centimetre	Combination of manual processes, and augmented GNSS, at a cost	Qualitative	L1, DFMC, PPP

A range of additional applications in the construction sector has been identified throughout this research but has not been quantified (or described qualitatively) for a range of reasons[141]. A collection of these applications is provided in the additional applications Chapter 18.

10.8 Assumptions and limitations

The economic modelling undertaken for this sector has been based on a combination of official data sources, desktop research, information provided by the Demonstrator Project as well as rational and logical assumptions. These

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[140] Case study obtained through Position Partners – Drone Deploy (n.d) Drone mapping in construction – case study. Retrieved from: https://www.dronedeploy.com/resources/ebooks/drone-mapping-construction-earthwork/

[141] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

assumptions have all been agreed in discussion with the relevant Demonstrator Project and FrontierSI.

In addition to standard caveats around economic modelling, the following assumptions and limitations are highlighted:

Year-on-year growth rate of fatalities and serious injuries

The year-on-year growth regarding fatalities and serious injuries for FFH and vehicle collisions were determined using 5–10-year historical year-on-year trends. This was then held constant for the modelling period of 30 years.

Serious injuries statistics

Data regarding serious injury claims were used as proxies. The data were obtained from Australian and New Zealand sources and are noted in footnotes and the bibliography.

Incidents due to vehicle collisions

No clear statistics could be obtained from the Australian and New Zealand databases regarding vehicle incidents in which collisions occurred. Thus, it was assumed that statistics regarding vehicle incidents reflected vehicle collisions causing fatalities and serious injuries.

Cost of vehicle damage and site downtime due to incidents on-site

Assumed to be four times the direct costs of serious injuries based on the desktop research noted in footnotes and the bibliography.

Cost of serious injuries for New Zealand sector

Assumed to be the same as Australia, which captures the associated costs to the wider economy along with direct costs to business owners and accident compensation schemes.

Present value discount

All quantitative benefits have been discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

Data points have been sourced from other Demonstrator Projects

To ensure consistency in modelling across all Demonstrator Projects, where similarities exist the relevant data points have been used consistently in the construction model.

Consumer sector

Key findings

The consumer sector is broad and encompasses location-based goods and services purchased by individuals, rather than by large manufacturers and industries. The sector uses standalone GNSS for a variety of activities from use in devices such as fitness watches and mobile phone applications for recreation to logistics management applications. The Demonstrator Projects within the consumer sector focussed on last mile delivery and smart healthcare applications.

Highlights

Total benefits of **PV AUD$34m** are anticipated in the consumer sector, represented by two Demonstrator Projects, from the deployment of the SBAS signals – L1 and DFMC – over a 30-year period. These benefits accrue exclusively to operating expenditure savings. Benefits attributable to PPP are not modelled as high receiver costs and re-convergence requirements were expected to present barriers to uptake. A selection of the benefits includes:

- 16m labour hours saved due to new and improved delivery tasks generated through enhanced positioning capabilities of automated delivery robots. This has the potential to result in operational savings of **PV$34m.**
- The SBAS signals are anticipated to reduce the work (labour hours) required to develop the requisite internal 3D maps for automated delivery vehicles.
- The SBAS signals can provide accurate positioning for assistive technologies for the visually and physically impaired which will support use of position-based alerts to help prevent and reduce the risk of incidents, such as trips, falls, and collisions.
- The accuracy and integrity that the SBAS signals provide can enable assistive technologies to be integrated with public transport systems, contributing to enhanced environmental awareness whilst enabling greater independence and increased participation in the economy.

It is important to note that the quantifiable benefits have only been derived for one category, within one Demonstrator Project. In this sense, the results represent a significant underestimation of the economic benefits that would be expected in the sector.

Quantifiable benefits

Figure CON1 – Benefits by geography (30-year, AUD)

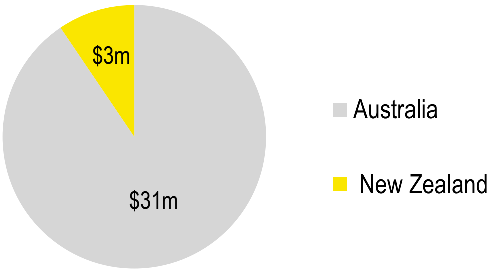
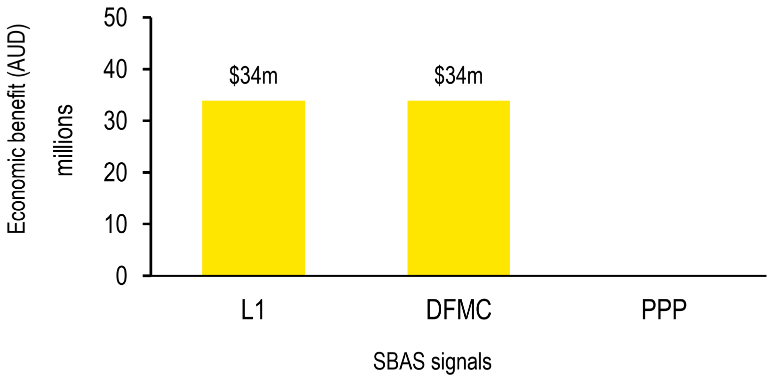


Figure CON2 – Benefits by signals (30-year, AUD)



11. Consumer sector

11.1 Sector description

The consumer sector is broad and encompasses location-based goods and services[142] purchased by individuals rather than by large manufacturers and industries[143]. Products sold in this sector vary significantly from televisions to mobile phones, grocery products, and services like package delivery and personal assistants. Given such a wide scope, the sector stands to have many applications that benefit from the use of the SBAS signals.

The purpose of this Chapter is to provide a sample of some of the applications and the benefits which can be anticipated from the sector, with a specific focus on last mile delivery and smart healthcare.

11.2 Use of positioning technology

Positioning technology currently plays a major role in the consumer sector and supports delivery tracking, providing directions to consumers through mobile phones and enabling assistive technologies such as wearable health watches. The positioning requirements of equipment within the consumer sector are often defined on a case-by-case basis owing to the intended function of the applications.

11.2.1 Last mile delivery

Last mile delivery is defined as the transport of goods between the supplier and consumer by postal and courier services[144].

As Australia and New Zealand customers increasingly shift to online shopping[145], their expectations of a reliable and quick service have driven greater demand within the sector. In 2017, there was a 49.2 percent increase in shipping consignments within Australia which was attributed to an increase in online shopping[146]. This increase in activity translates into an Australian online shopping industry worth $23 billion and $1 in every $20 from Australian consumers' being spent on e-commerce/online purchases in 2017[147]. In 2018, New Zealand spent $4.2 billion on online purchases, which was a 10 percent increase over 2017[148].

Last mile delivery depends on reliable supply chain processes to provide efficient and effective movement of goods[149,146]. Standalone GNSS provides greater in-transit visibility and tracking throughout the supply chain and when combined with sensor data allows for efficient decision making and processes. An example is an image sensor (infrared or ultraviolet) which can provide visible and real-time condition monitoring of the package combined with location information (obtained using standalone GNSS). This allows a supplier to know where a parcel is and ensure it is always in an optimum condition from supplier to its final destination[150].

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[142] Geoscience Australia. (n.d.) Positioning for the future. Retrieved from: http://www.ga.gov.au/scientific-topics/positioning-navigation/positioning-for-the-future

[143] Kenton, W. (2018) Consumer goods sector. Retrieved from: https://www.investopedia.com/terms/c/consumer-goods-sector

[144] Datex. (n.d.) What is last mile delivery? Retrieved from: https://www.datexcorp.com/last-mile-delivery-part-1-omni-channel-retail-affecting-transportation-logistics/

[145] Australia Post (2018) Inside Australian online shopping. Retrieved from: https://auspost.com.au/content/dam/auspost_corp/media/documents/2018-ecommerce-industry-paper-inside-australian-online-shopping.pdf

[146] Datex. (n.d.) What is Last Mile Delivery? Part 1: How Omnichannel Retail is Affecting Transportation & Logistics. Retrieved from: https://www.datexcorp.com/last-mile-delivery-part-1-omni-channel-retail-affecting-transportation-logistics/

[147] The state of e-commerce. (2017) Neto. Retrieved from: https://www.netohq.com/blog/neto-state-of-ecommerce-report-2018

[148] BNZ (2018) New Zealand online retail sales November 2018. Retrieved from: https://www.bnz.co.nz/business-banking/support/commentary/online-retail-sales-index

[149] Dolan, S. (2018) The challenges of last mile logistics & delivery technology solutions. Retrieved from: https://www.businessinsider.com/last-mile-delivery-shipping-explained/?r=AU&IR=T

[150] Deloitte (n.d.) Using smart sensors to drive supply chain innovation. Retrieved from: https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-cons-smart-sensors.pdf

11.2.2 Smart healthcare

Assistive technology is a common form of smart healthcare and can be defined as products, equipment, and systems that enhance learning, working, and daily living for persons with disabilities[151]. Specifically, assistive technology in combination with mobile applications leverages big data with positioning information to aid people with a range of impairments.

In 2016, Vision Australia estimated that there were 384,000 individuals in Australia who are blind or experience poor vision[152]. The New Zealand Blind Foundation estimates that there are 30,000 individuals affected by blindness or low vision[153]. It is noted that around four million Australians (83.9 percent) have physical impairment conditions[154] and 404,000 New Zealanders suffer from a physical limitation[155]. These statistics are only projected to increase significantly over time, thus it is of increasing importance for both nations to determine effective methods to manage and mitigate these disabilities to improve the quality of life of all citizens.

Understanding the precise position of a person with a disability is clearly an important component of assistive technologies. If the absolute position of a subject is inaccurate by a metre, then that can be the difference between placing them on the footpath or on the road. Determining an appropriate level of absolute positioning in a range of urban environments is also critical given the tendency for a range of GNSS signal distortions that can occur when operating in including urban canyons.

It is therefore no surprise that the European GNSS Agency, predicts that the use of standalone GNSS for healthcare and assistive technologies will continue to grow rapidly with a forecasted global uptake rate of 32 percent between 2016 and 2020[156]. Consequently, the need for improved assistive technologies, particularly those that utilise standalone and augmented GNSS for navigation and orientation, is increasing[157,158].

11.3 Demonstrator Project descriptions

Two Demonstrator Projects were commissioned to investigate the potential benefits of the SBAS signals to the consumer sector. Table CON1 details these Demonstrator Projects.

Table CON1 – Demonstrator Projects (Consumer Sector)

Demonstrator project	Description	Signals tested
Australia Post	Trialled the potential of the SBAS signals integrity and accuracy to improve standalone GNSS location to optimise and enhance unsupervised automated parcel delivery via automated footpath robots in last mile deliveries	L1, DFMC
QUT	Tested the use of the SBAS signals integrity and accuracy for use in special needs routing platforms and how it can contribute to making cities and attractions more accessible to physically and visually impaired people through enhanced positioning and guidance	L1, DFMC

11.4 Anticipated benefits

In seeking to understand the economic benefits for the consumer sector and the wider economy enabled by the SBAS signals, a benefits mapping exercise

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[151] Assistive Technology Australia (n.d.) Assistive technology. Retrieved from: https://at-aust.org/home/assistive_technology/assistive_technology

[152] Vision Australia. (n.d) Blindness and vision loss. Retrieved from: https://www.visionaustralia.org/information/newly-diagnosed/blindness-and-vision-loss

[153] Blind Foundation. (n.d.) Blindness and low vision in New Zealand – atest statistics. Retrieved from: https://blindfoundation.org.nz/eye-info/latest-statistics/

[154] Australian Human Rights Commission. (2005) National inquiry into employment and disability: Issues Paper 1. Retrieved from: https://www.humanrights.gov.au/publications/national-inquiry-employment-and-disability-issues-paper-1

[155] StatsNZ. (2014) Disability survey: 2013. Retrieved from: http://archive.stats.govt.nz/browse_for_stats/health/disabilities/DisabilitySurvey_HOTP2013/Commentary.aspx#mainlimit

[156] European GNSS Agency. (2017) GNSS market report issue 5. Retrieved from: https://www.gsa.europa.eu/system/files/reports/gnss_mr_2017.pdf

[157] Elmannai, W.and Elleithy, K. (2017) Sensor-based assistive devices for visually-impaired people: current status, challenges, and future directions. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5375851/#B1-sensors-17-00565

[158] Chanana, P., Paul, R. and Balakrishnan, M. (2017) Assistive technology solutions for aiding travel of pedestrians with visual impairment. Retrieved from: https://journals.sagepub.com/doi/full/10.1177/2055668317725993

was undertaken with each Demonstrator Project to identify how the benefits of SBAS flowed through to operational benefits. The following sections detail anticipated benefits by sub-sector.

11.4.1 Last mile delivery

At present, last mile delivery is seen by industry as inefficient and costly[159] as well as a high risk for the postal and courier services. For example, if a customer is not home, then a parcel may need to be to be redirected or redelivered another day. This can result in consumer dissatisfaction, delivery inefficiencies or additional costs. In some cases, last mile delivery can comprise 53 percent of the delivery costs for a parcel[160].

Companies like Amazon are trialling automated vehicles to address inefficiencies. These trials include footpath robots and helicopter UAVs that can deliver packages as either an alternative to traditional courier deliveries or more commonly an additional offering such as for after-hour deliveries or deliveries at designated times selected by the consumer[161,162].

It is anticipated that improvements in the positioning performance of automated delivery robots will improve their reliability and ease of use thereby improving this service offering.

The anticipated benefits of automated last mile delivery are:

Reduction in labour required during the robot setup phase

The SBAS signals are anticipated to improve the reliability and accuracy of on-board positioning receivers which are relied upon during the robot's setup phase at the start of each shift. As a result, the time required for an employee to oversee this phase will decrease. Practically, this will manifest in labour hours saved and can have a positive impact on the productivity of an employee as it can enable them to focus on other activities to support last mile delivery such as optimal planning of delivery routes for the week.

Reduction in labour during the mapping phase using robots

As noted earlier, when the robot is first deployed to a new suburb it is manually driven around to create an on-board 3D map (using its on-board sensors) that is well aligned to its actual geographic position in the world using GNSS.

It is anticipated that the SBAS signals can provide better alignment between the 3D map and the robot's geographic position and thereby has the potential to reduce the time required to conduct this activity. Moreover, the SBAS signals' have the potential to reduce potential mapping blackspots and the need to revisit areas for remapping. This all contributes to operational productivity.

Improved parcel delivery times

The SBAS signals can provide increased accuracy, allowing effective operation in a wider range of environmental conditions. This can increase the reliability of the system during deliveries and the ability to successfully deliver parcels at the correct destination with no human interference, whilst also minimising the risk of accidents on its journey. This improved reliability can reduce the time spent by a customer in locating the robot thus improving the efficiency of the offering.

11.4.2 Smart healthcare

The focus of the smart healthcare sub-sector is on SBAS-enabled applications that benefit visually and physically impaired persons who have long-term limitations in their ability to carry out daily activities[163].

In this Chapter, both blind and low-vision individuals will be referred to as visually impaired. Physical impairments are those that limit a person's physical capacity to be mobile, their dexterity, and stamina[164]. Other disabilities such as dementia may also benefit significantly from smart healthcare applications.

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[159] Lopez, E. (2017) Why is the last mile so inefficient? Retrieved from: https://www.supplychaindive.com/news/last-mile-spotlight-inefficient-perfect-delivery/443089/

[160] Australia Post. (2018) Inside Australian online shopping. Retrieved from: https://auspost.com.au/content/dam/auspost_corp/media/documents/2018-ecommerce-industry-paper-inside-australian-online-shopping.pdf

[161] Scott, S. (2019) Meet Scout – field testing a new delivery system with Amazon Scout. Retrieved from: https://blog.aboutamazon.com/transportation/meet-scout

[162] Amazon. (n.d.) Amazon Prime Air. Retrieved from: https://www.amazon.com/Amazon-Prime-Air/b?ie=UTF8&node=8037720011

[163] European GNSS Agency. (2017) GNSS market report issue 5. Retrieved from: https://www.gsa.europa.eu/system/files/reports/gnss_mr_2017.pdf

[164] House with No Steps (n.d.) Types of physical disabilities. Retrieved from: https://www.hwns.com.au/about-us/about-disability/types-of-disabilities/types-of-physical-disabilities/

Anticipated benefits then accrue to applications that seek to improve current assistive technologies, or look to create new applications that ultimately improve the quality of life for impaired persons. Specifically:

Reduced risk in incidents associated with trips, falls, and collisions

Through discussions with the Demonstrator Project and information provided, it has been noted that individuals with visually and physically impairments are increasingly susceptible to incidents when compared to the general population[165,166,167]. These incidents can include but are not limited to trips, falls, and collisions when navigating and orientating oneself[168].

Councils and businesses in Australia and New Zealand must provide facilities to ensure areas are accessible to the disabled such as the provision of audio-tactile signals at crossings[169]. However, there are still limitations that place these persons at risk. For example, an issue with audible signals at crossings is that they are set on timers and operate independently from dynamic and real-world hazards such as reckless drivers[170].

Some of the other highlighted causes reported by visually and physically impaired individuals[166,167] are: the lack of tactile ground surface indicators, existence of obstacles on footpaths such as other pedestrians, difficulty reading bus numbers and reduced ability to hail a bus, disorientation, and crossing streets carefully to avoid being hit by vehicles or cyclists.

The provision of haptic belts to assist in identifying objects and hazards can limit the extent to which trips, falls, and collision risks occur. These applications place significant reliance on absolute positioning information to essentially guide a user through complex urban areas.

Enhanced mobility leading to greater autonomy

In addition to the risk of incidents that visually and physically impaired individuals are prone to, another major challenge is the ability to maintain independence and autonomy, which can often be measured in the context of mobility[171].

Mobility describes an individual's ability to move their body within or between locations and the ability to manipulate objects[172]. For physically and visually impaired individuals, travelling from one destination to another is difficult as they are not able to be as mobile, or use mobility services, as efficiently as able-bodied people.

As well as helping reduce the risk of trips, falls, and collisions, haptic belts can assist users navigate complex urban areas – including footpaths, crossing roads, and catching public transport. This increased mobility can result in a greater sense of autonomy which can have positive impacts on quality of life for the visually and physically impaired.

Reduction in direct and indirect costs to the economy

In 2016, a study estimated that the economic impact and cost of vision impairment in Australia was up to $9.85b[173]. This includes the direct costs of mitigating the negative effects of impairment including the $50 foldable long cane that has been in use for 75 years, the guide dog which alone costs more than $30,000 to train, as well as costs to provide and maintain supporting

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[165] Maduchi, R. and Kurniawan, S. (2011) Mobility-related accidents experienced by people with visual impairment. Insight: Research and Practice in Visual Impairment and Blindness.

[166] Liu, S., Oxley, J., Bleechmore, M., Langord, J. (n.d.) Mobility, safety and xperiences of blind and low vision pedestrians in Victoria, Australia

[167] Wood, J., Lacherez, P., Black, A., Cole, M., Boon, M. and Kerr, G. (2011) Risk of falls, injurious falls, and other injuries resulting from visual impairment among older adults with age-related macular degeneration. Investigative Ophthalmology & Visual Science, 52(8).

[168] Taylor, H., Pezzullo, M. and Keeffe, J. (2006) The economic impact and cost of visual impairment in Australia. British Journal of Ophthalmology, doi:10,1136/bjo.2005.089986

[169] Mobility Research Centre (n.d.) Australian & New Zealand standards/guidelines. Retrieved from: https://www.mobilityresearch.co.nz/standards

[170] Burtt, D., (2014) Road safety audit tool for pedestrians who are vision impaired. Vision Australia (Victoria, Melbourne). Retrieved from: http://www.victoriawalks.org.au/Assets/Files/Vision_Impaired_Road_Safety_Audit_Tool.pdf

[171] Sachdeva, N. and Suomi, R. (n.d.) Assistive technology for totally blind – barriers to adoption. Retrieved from: https://www.mn.uio.no/ifi/english/research/news-and-events/events/conferences-and-seminars/iris2013/groups/iris36_submission_16.pdf

[172] Cowan, R., Fregly, B., Boninger, M., Chan, L., Rodgers, M. and Reinkensmeyer, D. (2012) Recent trends in assistive technology for mobility. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3474161/

[173] Taylor, H., Pezzullo, M. and Keeffe, J. (2006) The economic impact and cost of visual impairment in Australia. British Journal of Ophthalmology, doi:10,1136/bjo.2005.089986

infrastructure such as audio-tactile pedestrian push buttons at intersections[174].

The $9.85b cost also includes the indirect costs to the health system such as those due to falls and the subsequent treatments required. Further indirect costs include loss of income due to the impairment, cost of carers and aids, and the non-financial costs from a decreased quality of life[175].

The provision of haptic belts and wider assistive technologies can all help to reduce these direct and indirect costs to individuals and the wider economy.

Anticipated benefits for the consumer sector have been classified into the benefit categories in Table CON2 below.

Table CON2 – Consumer sector benefit categorisation

Benefit	Benefit category	Quantitative?
Reduction in labour required during the robot setup phase	Operating expenditure savings	Yes
Reduction in labour required during the mapping phase using robots	Operating expenditure savings	No
Improved parcel delivery times	Operating expenditure savings	No
Reduced risk of incidents associated with trips, falls, and collisions	Health and safety	No
Enhanced mobility, leading to greater autonomy	Health and safety	No
Reduction in direct and indirect costs to the economy	Operating expenditure savings	No

11.5 Positioning needs and current methods

There are no known regulatory requirements when it comes to positioning in the consumer sector as these vary depending on the application and environment. The purpose of this section is to detail these positioning needs (and current methods) to the extent possible.

11.5.1 Last mile delivery

Currently automated footpath delivery robots use sensors and navigation technologies to transport goods such as packages around an open space without the need of a human to control them[176]. This service in the sector is intended to be an added service to the traditional methods of delivery such as that through delivery couriers.

The robot used is defined by the Demonstrator Project as a human-sized four-wheeled vehicle designed to be fully automated and capable of path planning and obstacle avoidance. A compartment on the top carries up to five packages and the front of the robot contains cameras and LiDAR scanner.

Like other existing delivery robots, this one is also equipped with a standalone GNSS receiver[177]. The robot determines its absolute position in real time using on-board hardware integrated with standalone GNSS and a suite of other sensors, including odometry, inertial sensing, and LiDAR[177].

The navigation system fuses odometry, inertial sensors, and LiDAR information to track the robot's position accurately in real time[177]. These all work together to position the robot whilst providing the ability to detect surrounding pedestrians and other obstacles, allowing for deployment of emergency braking where necessary and the activation of collision avoidance systems (as shown in Figure CON3)[177].

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[174] Guide Dogs (n.d.) Frequently asked questions – How much does it cost to train a guide dog? Retrieved from: https://www.guidedogs.org.au/frequently-asked-questions

[175] Ruffa, A.J., Stevens, A., Woodward, N. and Zonfrelli, T. (2015) Assessing ibeacons as an assistive tool for blind people in Denmark. Retrieved from: https://web.wpi.edu/Pubs/E-project/Available/E-project-050115-131140/unrestricted/iBeacons_IQP_final.pdf

[176] Office of Inspector General United Postal Service (2018) RARC report autonomous mobile robots and the postal service. Retrieved from: https://mailomg.files.wordpress.com/2018/04/autonomous-mobile-postal-robots.pdf

[177] Information provided by a Demonstrator Project.

Figure CON3 – Automated footpath delivery robot utilising LiDAR with standalone GNSS to navigate[172]

Adapted from RARC Report

However, due to the performance and precision of standalone GNSS in complex urban environments, the positioning information processed by the robot does not account for these errors[178]. As a result, the capability of the robot to accurately position itself can be compromised.

11.5.1.1 Reduction in labour required during the robot setup phase

When a robot is first switched on and setup for deliveries by an operator, it needs to reconcile its current on-board 3D map location with the position coming for its real-time sensors. It uses standalone GNSS to perform initial alignment between these two sources. This setup phase is crucial to automated navigation during deliveries.

The robot then uses information from onboard sensors such as cameras and LiDAR for subsequent precise alignment to the 3D map to determine the absolute position of a robot. The overall reliability of these steps is heavily influenced by the standalone GNSS precision and accuracy in the coarse alignment step[179].

Due to the imprecision of standalone GNSS, the initial alignment step often needs to be repeated by the operator to obtain absolute positioning, in a process that can take up to 10 minutes[179].

Achieving more reliable positioning as a result of the SBAS signals has the potential to speed up this step which will result in benefits to productivity as operators/employees can instead focus on other tasks crucial to last mile delivery. Examples include planning for incoming parcels from manufacturers, planning routes for upcoming deliveries, and managing the overall process to ensure the customer experience is optimal[179].

Conversations with the sector suggest that the use of SBAS signals can bring automated delivery from metre to sub-metre level accuracies[179].

11.5.1.2 Reduction in labour required during the mapping phase using robots

Each automated delivery robot needs to build a 3D map of a new suburb it will be operating in when it is initially deployed there. This is done through a process called simultaneous localisation and mapping (SLAM)[179]. This step relies on its on-board sensors and standalone GNSS to generate and ingest information.

To build the map, an operator (currently an engineer) manually drives the robot around its environment as it uses standalone GNSS to determine the rough structure of the environment and its additional sensors to infer the robot's path with high accuracy, thereby providing an optimised map. The standalone GNSS position of the system is continually tracked and registered to the map along the delivery route.

Effectively, the locations that the standalone GNSS provides during the mapping exercise are averaged to determine the relationship between the map and the standalone GNSS coordinate system[179].

More precise GNSS, such as RTK, can be utilised for more accurate maps; however, the Demonstrator Project notes that this is not always feasible in urban areas and there are additional costs required to access the signals. In contrast, when the SBAS signals are operational, they will be available at no

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[178] Office of Inspector General United Postal Service (2018) RARC report autonomous mobile robots and the postals. Retrieved from: https://mailomg.files.wordpress.com/2018/04/autonomous-mobile-postal-robots.pdf
[179] Information provided by a Demonstrator project.

additional cost to the users and can be compatible with existing GNS receivers.

11.5.2 Improved parcel delivery times

While robots are navigating urban environments, standalone GNSS is used to provide a sanity check on the rest of the navigation system to ensure the entire system is reliable. Unfortunately, the accuracy of standalone GNSS is subject to errors due to geographic features in dense and urban environments.

Currently, off-the-shelf geocoding is used to provide the delivery location (GNSS coordinates for a given property). Unfortunately, this is often at the centre point of a rooftop which is not particularly useful as an end-point delivery coordinate for a robot, as it does not represent a convenient location for the customer to meet the robot for their parcel[180]. Every minute that is spent by the customer locating the robot, is a minute that robot is not delivery parcels, degrading the efficiency of the offering[180].

The SBAS signals are anticipated to assist in providing more accurate and reliable positioning information as they are less prone to errors in urban environments.

11.5.3 Smart healthcare

All the anticipated benefits in the smart healthcare sub-sector identified above revolve around the performance of various assistive technologies, specifically travel and navigation aids, and include but are not limited to haptic belts and wearable technologies such as smart watches.

Visually or physically impaired individuals currently rely on traditional travel and navigation aids such as long canes, wheel chairs, and guide dogs for overcoming mobility challenges[180]. Long canes are the most commonly used assistive device as they increase the detection range to nearly a metre and provide information about ground-level surfaces to the user[181,182].

There are many limitations to the long cane including uncertainty regarding steep descents in the pathway, danger of tripping over objects in crowded places, and no protection for the upper body from hanging or protruding obstacles[183].

These limitations have resulted in the growth of assistive technologies. Limitations of traditional assistive solutions have then led to the development of more advanced assistive aids that utilise GNSS to help guide the user by providing the required orientation and navigation information[184]. In combination with sensors, GNSS helps the user avoid unwanted collisions resulting for example in a fall.

Examples of a GNSS-enabled assistive technology include wearables in the form of a wrist watch or belt design that can track a four-metre path around the user to detect obstacles and locations (as shown in Figure CON4)[183,185,186].

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[180] Information provided by a Demonstrator project.

[181] New Zealand Transport Agency (2015) RTS 14 – guidelines for facilities for blind and vision impaired pedestrians. Retrieved from: https://www.nzta.govt.nz/assets/resources/road-traffic-standards/docs/rts-14.pdf

[182] Chanana, P., Paul, R. and Balakrishnan, M. (2017) Assistive technology solutions for aiding travel of pedestrians with visual impairment. Journal of Rehabilitation and Assistive Technologies Engineering. 3. Retrieved from: https://journals.sagepub.com/doi/full/10.1177/2055668317725993

[183] feelSpace (n.d.) naviBelt. Retrieved from: https://www.feelspace.de/?lang=en

[184] Sachdeva, N. and Suomi, R. (n.d.) Assistive technology for totally blind – barriers to adoption. Retrieved from: https://www.mn.uio.no/ifi/english/research/news-and-events/events/conferences-and-seminars/iris2013/groups/iris36_submission_16.pdf

[185] Ramadhan, A. (2018) Wearable smart system for visually impaired people. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5877379/

[186] Montenegro, R. (2016) How a directional belt for the blind could create a sixth sense. Retrieved from: https://bigthink.com/robert-montenegro/vibrating-belt-for-the-blind

Figure CON4 - Assistive technologies intended to aid visually and physically impaired people with navigating to their desired locations

Ramadhan, A. (2018). Wearable smart system for visually impaired people.

feelSpace (n.d.). naviBelt.

Wearable technologies generally utilise standalone GNSS, ultrasonic sensors, and a smartphone as a form of communication to navigate to destinations through haptic vibrations, and alert the user to surrounding hazards through a buzzer[187]. This alarm assists in preventing people from unwanted collisions, tripping, and falling, whilst guiding them to their desired destination.

SBAS has the potential to improve the performance of these technologies by providing more accurate and reliable positioning information in urban environments and other challenging conditions.

11.6 Sector benefits

The following sections detail the benefits of SBAS relative to the status quo, describes the anticipated economic impact, and how those benefits accrue depending on the signals used.

11.6.1 Signal attribution

As shown in Table CON3, benefits in relation to the use of SBAS in automated delivery robots are expected to accrue evenly across L1 and DFMC given their ability to provide instantaneous sub-metre accuracy. Whilst PPP provides greater accuracy levels, the cost of PPP receivers, are expected to present a barrier to meaningful uptake and hence unsuitable for this application.

The benefits in relation to the use of SBAS in smart healthcare are expected to accrue evenly across L1 and DFMC. Demonstrator Projects have advised that PPP receivers a likely not to be commercially viable under current circumstances[188]. However, this does not preclude the possibility that future applications will require higher accuracy and adopt PPP. It is also possible that the cost of PPP receivers will become more affordable in the future.

These indicative test results have been provided by FrontierSI as representative results of the testing carried out by the SBAS Demonstrator Projects in this sector. Values are presented at a 95 percent confidence interval. Where deviations exist, DFMC SBAS results are expected to be similar to SBAS L1 in an operational system. All benefits are expected to accrue to horizontal accuracy unless stated.

The testing was carried out in lightly obstructed environments with consumer equipment.

Table CON3 – Consumer sector signal attribution

Signal	Consumer sector test results	
	Expected horizontal performance (m)	Expected vertical performance (m)
SBAS L1	2.1	4.0
SBAS DFMC	3.0	5.8
PPP	-	-

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Quantitative benefits					
Reduction in labour required during the robot setup phase	Metre to sub-metre	100%	100%	0%	PPP receiver costs too high for use in consumer sector
Qualitative benefits					
Reduction in labour required during the mapping phase using robots	Metre to sub-metre	✓	✓	-	PPP receiver costs too high for use in consumer sector

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[187] Ramadhan, A. (2018) Wearable smart system for visually impaired people. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5877379/; Montenegro, R. (2016) How a directional belt for the blind could create a sixth sense. Retrieved from: https://bigthink.com/robert-montenegro/vibrating-belt-for-the-blind; and Information provided by a Demonstrator Project.

[188] Information provided by a Demonstrator Project.

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Improved parcel delivery time	Metre to sub-metre	✓	✓	-	PPP receiver costs too high for use in consumer sector
Reduced risk in incidents associated with trips, falls and collisions	Metre to sub-metre	✓	✓	-	PPP receiver costs too high for use in consumer sector
Enhanced mobility, leading to greater autonomy	Metre to sub-metre	✓	✓	-	PPP receiver costs too high for use in consumer sector
Reduction in capital and operational costs to the wider economy	Metre to sub-metre	✓	✓	-	PPP receiver costs too high for use in consumer sector

11.6.2 Uptake rate

An S-curve uptake curve has been deployed for all benefits regarding last mile delivery. This reflects discussion with the sector which suggests slow initial uptake reflected by early adopters, followed by exponential uptake as the effectiveness of the technology is realised by the rest of the market and a steady plateau in the long run reaching a maximum of 50 percent over the 30-year forecast period. Discussions with the sector has resulted in the saturation point being set at 50 percent to reflect uptake and sensitivities in the sector.

An S-curve uptake curve is also assumed to occur for benefits associated with smart health through enhanced performance and capabilities of assistive technologies. This reflects discussion with the sector which suggests slow initial uptake as the sector will want to see proof of effectiveness, followed by exponential uptake as the market come to realise the benefits of SBAS-enabled enhanced assistive technologies and then a steady plateau in the long-run.

11.6.3 Quantitative benefits – last mile delivery

11.6.3.1 Reduction in labour required during the robot setup phase

Over a 30-year assessment period, it is anticipated automated delivery robots enabled by the SBAS signals in Australia and New Zealand will provide a total of 16m hours unlocked for other tasks from reduction in the labour required to set-up the delivery robots at the start of each delivery shift. This results in a potential PV$34m worth of economic savings.

A key challenge in quantifying this benefit was determining the number of automated delivery robots that would be deployed across Australia and New Zealand respectively. Discussions with the Demonstrator Project concluded it would be suitable to derive the number of robots according to the number of metropolitan suburbs, as these areas would have good GNSS coverage and be near distribution centres. The Demonstrator Project anticipates that there would be five delivery robots per suburb.

Neither the Australian Bureau of Statistics (ABS) nor Statistics New Zealand (Stats NZ) directly and uniformly define metropolitan suburbs; however, each agency provides statistics regarding geographic areas that were used as a proxy for metropolitan suburbs[189,190].

For example, the best Australian definition of a metropolitan area is a Statistical Area Level 2 (SA2). This is an area with populations of 3,000 to 25,000[189]. This definition does not align with the New Zealand definition of an equivalent metropolitan area, which contain up to 5,000 residents[190].

It has been assumed that the definition of an SA2 is the correct spatial size for a metropolitan area as this aligns with the definition of a metropolitan suburb provided by the Demonstrator Project. This definition has then been used to derive an equivalent New Zealand suburb count.

The urban population ratio between New Zealand and Australia was first derived and then used to discount the 1,721 Australian metropolitan suburbs defined by urban SA2s. In 2016, Australia's urban population was 89.6 percent of the total population, whilst New Zealand's urban population was 86

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[189] Australian Bureau of Statistics. (n.d.) Australian statistical geography standard (ASGS). Retrieved from: http://www.abs.gov.au/websitedbs/d3310114.nsf/home/australian+statistical+geography+standard+(asgs)

[190] StatsNZ (2017) Statistical standard for geographic areas 2018. Retrieved from: http://archive.stats.govt.nz/methods/classifications-and-standards/classification-related-stats-standards/geographic-areas.aspx

percent of the total population[191]. This resulted in a population ratio of roughly 19 percent. Using this value as a discount rate resulted in 322 New Zealand metropolitan suburbs, making a total of 2,043 metropolitan suburbs between Australia and New Zealand.

The number of metropolitan suburbs and five robots per suburb each year[192] was held constant for the modelling period of 30 years. The number of delivery robots required each year was then multiplied by the time it took to setup the robots per year, which is 10 minutes per robot, given that they work 312 days per year[192].

This value was then multiplied by the hourly cost of labour to ascertain the labour cost savings. The Australian labour cost was provided by the Demonstrator Project. For New Zealand, the average hourly rate of a mail and parcel sorter was an equivalent and used as the proxy[193].

These results where then adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table CON4.

Table CON4 – Reduction in labour required during robot setup phase (30-year calculation)

Factor	Value	Notes
Number of metropolitan suburbs	2,043	Total Australia and New Zealand metropolitan suburbs
Total number of robots required in metropolitan suburbs over 30 years	306,500	Assuming five robots required per metropolitan suburb each year, over 30-year period
Total labour hours saved by reducing time required to set-up the robot	16m hours	Assuming all the time saved due to the robot's positioning component and 10 minutes time saving per setup
Labour cost savings during setup phase	$392m	Hourly cost of labour in each jurisdiction
Labour cost savings during setup phase adjusted for uptake	$118m	Adjusted for uptake using S-curve (50 % cap)
Present value	$34m	Discounted at 6.5%

Note: Totals may not sum due to rounding

11.6.4 Qualitative benefits – last mile delivery

11.6.4.1 Reduction in labour required during the mapping phase using robots

Discussions with the sector acknowledged that the use of the SBAS signals can contribute to better alignment between the 3D map and the robots' actual geographic position in the world. This has the potential to reduce the time required to conduct this activity, potentially cutting down the time required by an operator (currently an engineer) to manually drive the robot for it to build the map.

Additionally, the SBAS signals' accuracy and integrity can potentially reduce blackspots and the need to revisit areas for remapping. Overall, this unlocks labour hours that can be used for other last mile delivery tasks that could address the inefficiency issues, leading to improvements in operational productivity.

The precise number of labour hours that can be reduced is challenging to quantify and ultimately depends on a function of the following inputs[194]:

- The total scans by LIDAR needed
- The size of the area to map
- The maximum distance of the distance sensor

Given that these are unknown at this stage, a formal quantitative or qualitative estimate of reduced labour hours has not been possible.

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[191] Trading Economics. (n.d) Australia - urban population (% of total) Retrieved from: https://tradingeconomics.com/australia/urban-population-percent-of-total-wb-data.html and StatsNZ (n.d.) Urban and rural migration. Retrieved from: http://archive.stats.govt.nz/browse_for_stats/population/Migration/internal-migration/urban-rural-migration.aspx

[192] Information provided by a Demonstrator project.

[193] CareersNZ (n.d.) Mail and parcel sorter. Retrieved from: https://www.careers.govt.nz/jobs-database/transport-and-logistics/transport-logistics/mail-and-parcel-sorter/

[194] Robotshop (2018) 2D robot mapping software for autonomous navigation. Retrieved from: https://www.robotshop.com/community/robots/show/2d-robot-mapping-software-for-autonomous-navigation

11.6.5 Improved parcel delivery time

The SBAS signals are designed to be more accurate than standalone GNSS[195]. This can increase the reliability of the system and consumer confidence in automated delivery robots to successfully deliver parcels at the correct place along with minimal risk of accidents[195].

It was noted by the Demonstrator Project, that every minute a robot spends waiting for the customer to locate it would be a minute the robot was not delivering parcels, degrading the efficiency of the offering. The Demonstrator Project notes that the robots will wait up to five minutes before abandoning delivery.

Mapping with an SBAS-enabled device can provide more precise coordinates of delivery end-points that unsupervised robots will rely on, thereby improving the service offering[196].This can improve customer experience and increase the chances of using the service again.

Future implementations of the system could possibly incorporate app-based tracking, which can relay to the customer where exactly the robot is located at any given time.

Information provided by the Demonstrator Project also indicates that if the robot's navigation system fails (LIDAR, SLAM equipment etc.), it can utilise the SBAS-enabled GNSS equipment to continue navigating with more confidence, until an operator arrives.

11.6.6 Qualitative benefits – smart healthcare

This section qualitatively describes the potential role of the SBAS signals in the application of special needs routing/assistive technology to aid visually and physically impaired individuals. The SBAS signals were used for special needs routing in three types of urban areas, specifically suburban areas, central business districts, and tourist attractions[197].

11.6.6.1 Reduced risk in incidents associated with trips, falls and collisions

One in 12 visually impaired individuals in the state of Victoria has been hit by a vehicle or bicycle while walking[198] and conversations with the Demonstrator Project expect this to reflect experiences of visually and physically impaired individuals across Australia and New Zealand[199].

It is notable that in most instances, these incidents occurred despite the visually impaired individuals being with their guide dogs and despite hearing the audible signals at intersections[200]. The audible signal is heavily relied on by visually impaired individuals as it indicates when it is safe to walk as all vehicles should have stopped to give way (such as those described in section 11.5.2).

Discussions with the sector show that SBAS-enabled assistive technologies can play a vital role in reducing the risk of trips, falls, and collisions. The SBAS signals can provide more accurate (metre to sub-metre) positioning of the individual with respect to their surroundings (e.g. roads, vehicles, and people), whilst providing the user with greater certainty about their position. Users will therefore have more confidence and trust in the technology to alert and prevent them from incidents as they navigate.

Moreover, should SBAS signals be used in conjunction with sensors found in assistive technologies (such as those described in section 11.5.2) the buffer zones for hazard detection could potentially be reduced significantly to sub-metre, thereby reducing the risk of false positives. This technology can also be more confidently used to complement existing urban infrastructure such as audible traffic signals to ensure that it is safe to cross roads.

11.6.6.2 Enhanced mobility, leading to greater autonomy

Through discussions with the Demonstrator Project, one of the main issues that visually and physically impaired individuals face regarding mobility when navigating in urban areas is the use of public transport.

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[195] Sanchez, D., Berges, C. and GMV S.A. (2006) The EGNOS SBAS message format explained. Retrieved from: https://gssc.esa.int/navipedia/index.php/The_EGNOS_SBAS_Message_Format_Explained#Message_Types_34.2C_35_and_36_Integrity_Messages

[196] Information provided by a Demonstrator project.

[197] StatsNZ (2014) Disability survey: 2013. Retrieved from: http://archive.stats.govt.nz/browse_for_stats/health/disabilities/DisabilitySurvey_HOTP2013/Commentary.aspx#mainlimit

[198] Carey, A. (2012) Risks for blind pedestrians on rise. Retrieved from: https://www.theage.com.au/national/victoria/risks-for-blind-pedestrians-on-rise-20121230-2c1h8.html

[199] Liu, S., Oxley, J., Bleechmore, M. and Langord, J. (2012) Mobility, safety and experiences of blind and low vision pedestrians in Victoria, Australia. Retrieved from: http://acrs.org.au/files/arsrpe/Liu%20et%20al%20-%20Safety%20mobility%20and%20experiences%20of%20blind%20and%20low%20vision%20pedestrians%20in%20Victoria.pdf

For example, in Brisbane, the public transport fleet is reported to lack audio-visual announcements to identify approaching buses, trains, and stops[200]. As a result, impaired individuals are unable to hail their buses or easily communicate with the bus drivers. This means there is a higher risk of them missing the bus or having to find other means of arriving at their destination which can have an impact on their personal autonomy.

In addition to the reduced ability to utilise public transport, there is also a heightened risk of near misses, incidents and bad experiences with public transport. In addition to the direct impacts of these experiences, Monash University and Vision Australia[201] report that there are long-term psychological consequences so that after these incidents individuals have had significantly less confidence in being independent pedestrians.

Through further discussions with the sector, it is anticipated that these assistive technologies can potentially be integrated with transport networks such as a live schedule for buses and the audio-visual announcements at bus stops. This can help individuals achieve greater independence. For example, they could flag down a bus as it approaches a stop through a haptic or audible notice by the assistive technology. This can help with navigation within a city and with the more general sense of security and control, particularly in unfamiliar environments.

11.6.6.3 Reduction in direct and indirect costs to the economy

A wide range of activities and interventions can help lower the direct and indirect cost of harm prevention for physically and visually impaired individuals.

Brisbane City Council (BCC) is an example of a council which is committed to making its city accessible and inclusive[202]. In 2012 BCC invested a proportion of $200m to implement their first Access and Inclusion Plan which sought to improve the quality of life for many visually and physically impaired residents by improving how they could navigate in the city.

As a result, BCC strengthened their investment in further initiatives such as providing more tactile ground indicators at bus stops to indicate where to board, more audio-tactile pedestrian push buttons at intersections, and hearing devices at tourist attractions[203]. These costs are assumed to be included in the $9.85b figure that describes the cost of disabilities to the economy[204].

Assistive technologies can provide a further viable alternative to improve quality of life as it can reduce the risk of incidents and thereby reduce the consequential associated costs to the wider economy. They can also bridge the gap between what the council can and cannot currently offer such as audio-visual announcements at all bus stops.

Discussions with the Demonstrator Project anticipate that assistive technologies can also reduce the need for city councils to provide tactile paving and would provide a more scalable solution than beacon-based guidance systems. This can potentially reduce the significant upfront and maintenance costs currently incurred.

The SBAS signals can aid the development of assistive technologies and unlock new ways to use them. For example, they can inform future government decisions through a better understanding of how cities can support the blind and visually impaired to stay mobile, active, and productive as they navigate in their daily lives.

11.7 Summary

Table CON5 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning. The quantifiable economic impact of L1 and DFMC in the consumer sector is anticipated to be **PV AUD $34m** over 30 years.

This economic assessment represents a significant discount to what is possible in practice as it has been limited to the benefits of two sub-sectors. Moreover, only one of the benefit categories could be quantified.

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[200] Brisbane City Council (n.d.) Chapter 1 Pedestrian mobility and transport. Brisbane Access and Inclusion Plan 2012–2017. Retrieved from: https://www.brisbane.qld.gov.au/sites/default/files/20141806_-_pages_from_access_and_inclusion_plan_2012-2017_part1.pdf

[201] Vision Australia. (n.d) Blindness and vision loss. Retrieved from: https://www.visionaustralia.org/information/newly-diagnosed/blindness-and-vision-loss

[202] Brisbane City Council (2017) Accessibility access improvement program. Retrieved from: https://www.brisbane.qld.gov.au/sites/default/files/20171012_-_accessibility_improvement_program_fact_sheet.pdf

[203] Information provided by a Demonstrator project.

[204] Taylor, H., Pezzullo, M. and Keeffe, J. (2006) The economic impact and cost of visual impairment in Australia. British Journal of Ophthalmology, doi:10,1136/bjo.2005.089986

Moreover, because PPP was not tested by the two Demonstrator Projects, economic benefits have not been presented. However, it is worth clarifying that this fact may not be reflective of the potential importance of PPP to the consumer sector in practice.

Table CON5 – Benefits summary for the consumer sector (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Reduction in labour required during the robot setup phase	Metre to sub-metre	Standalone GNSS for coarse alignments with the onboard 3D map	16m hours of labour unlocked contributing to a total of AUD $34m savings	L1, DFMC
Reduction in labour required during the mapping phase using robots	Metre to sub-metre	Standalone GNSS to determine the difference between sensor inputs and a robot's position	Reduction in labour required for engineers to manually drive the robot to create a map of an area it will service	L1, DFMC
Improved parcel delivery times	Metre to sub-metre with signal integrity	Standalone GNSS with off-the-shelf geocoding (GNSS coordinates for a property)	More precise delivery coordinates and reduced risk of accidents, improving service offering	L1, DFMC
Reduced risk of incidents associated with trips, falls and collisions	Metre to sub-metre	Standalone GNSS receivers in assistive technologies	Improved capability of assistive technology to alert and prevent users from trips, falls and collisions	L1, DFMC
Enhanced mobility, leading to greater autonomy	Metre to sub-metre	Standalone GNSS receivers in assistive technologies	Integration of assistive technology with transport networks to improve accessibility and capability of impaired individuals to travel autonomously.	L1, DFMC
Reduction in capital and operational costs to the wider economy	Metre to sub-metre	Foldable white canes and guide dogs	Assistive technologies to improve quality of lives. This can reduce the costs borne by the wider economy because of incidents such as trips, falls and collisions.	L1, DFMC

A range of additional applications in the consumer sector have been identified throughout this research but the applications have not been quantified (or described qualitatively) for a range of reasons[205]. A collection of these applications is provided in the additional applications Chapter 18.

11.8 Assumptions and limitations

The economic modelling undertaken for this sector has been based on a combination of official data sources, desktop research, information provided by the Demonstrator Project as well as rational and logical assumptions. These assumptions have all been agreed in discussion with the relevant Demonstrator Project and FrontierSI.

In addition, to standard caveats around economic modelling, the following assumptions and limitations are worth highlighting.

11.8.1 Consumer sector

Limitation of quantitative analysis

Only one benefit category was quantified for the sector and was only reflective of one sub-sector. This was due to the limited amount of information that could be provided by the Demonstrator Projects, sector experts, and what is currently available to the public. Thus, it can be assumed that the

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[205] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

benefit of the SBAS signals to the sector can be more than what has been modelled.

11.8.2 Last mile delivery

Number of metropolitan suburbs

The number of Australian metropolitan suburbs were derived by determining the number of urban SA2s in the country, provided by Australia Bureau of Statistics. The urban population ratio between Australia and New Zealand was then used to discount the number of Australian metropolitan suburbs and used as a proxy for the number of New Zealand metropolitan suburbs.

Hourly cost of labour in New Zealand

The cost of labour for a similar organisation to the Demonstrator Project in New Zealand could not be provided thus the cost of labour provided by a statistical database was used. This was obtained by assuming the employee responsible for operating the robot would have a role equivalent to a mail and parcel sorter, in which the average hourly rate was used which is NZ$18.50 per hour.

Cost of labour

A Demonstrator Project advised that employees responsible for operating the robots would be working 40 hours per week. This was used to ascertain the hourly rate of Australian staff from an annual salary that was also provided by the Demonstrator Project).

Present value discount

All quantitative benefits have been discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

11.8.3 Smart healthcare

Limitation of qualitative analysis

This sector was assessed qualitatively due to the nature of the assessment and what could be ascertained through desktop research. However, given the growth in people with visual impairments (and other disabilities such as dementia) on the rise, it can be assumed that the benefits due to the use of the SBAS signals in smart healthcare applications will be significant.

Maritime sector

Key findings

The maritime sector is vitally important to both the Australian and New Zealand economies and facilitates trade, supports tourism activities and enables a range of recreational endeavours to take place. Optimising maritime operations through greater utilisation of position technology can have a number of economic benefits.

Highlights

Total benefits of **PV AUD$588m** are anticipated in the maritime sector from the deployment of the SBAS signals – L1, DFMC and PPP – over a 30-year period. A selection of these benefits consists of:

- 60,000 port-side labour hours saved during blackout events due to enhanced redundancy afforded by SBAS, which minimises disruption to port planning. This is anticipated to generate a **PV$205m** saving over a 30-year period.
- **PV$168m** in operating expenditure savings over a 30-year period associated with reduced time taken to complete post-processing of hydrographic surveying data.
- **PV$97m** in improved cargo shipping efficiency for a selected Australian port over a 30-year period as under keel clearance (UKC) is more effectively managed.
- **PV$53m** in operating expenditure savings for Sydney Harbour over a 30-year period associated with increased harbour capacity owing to improved confidence in portable pilot unit outputs.
- 16,000 misplaced containers avoided during blackout events due to enhanced redundancy afforded by SBAS generating **PV$28m** in operational savings over a 30-year period.

It is important to note that several maritime benefits have not been quantitatively scaled across the sector, or across jurisdictions, given the unique arrangements of harbour environments in particular. Most relevant are the UKC benefit, increased vessel capacity in harbour and increased harbour capacity through real-time navigation. In principle, it is expected that benefits would accrue across other ports in Australia and New Zealand but to a greater or lesser degree than described in this Chapter, depending on the specific characteristics of each port.

Quantifiable benefits

Figure MA1 – Benefits by benefit category (30-year, AUD)

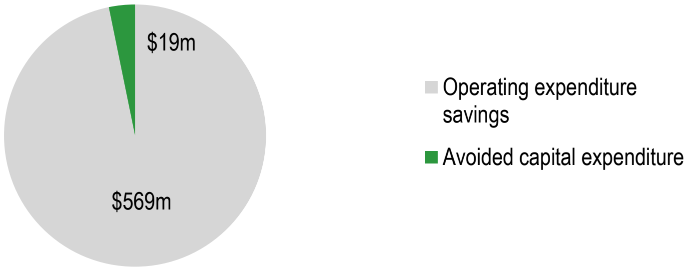


Figure MA2 – Benefits by geography (30-year, AUD)

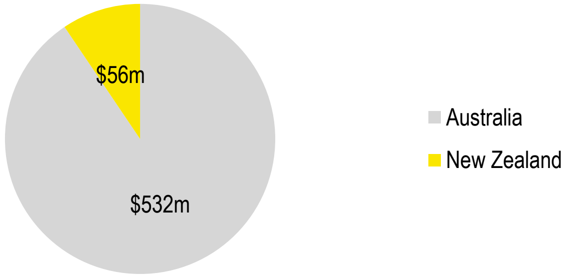
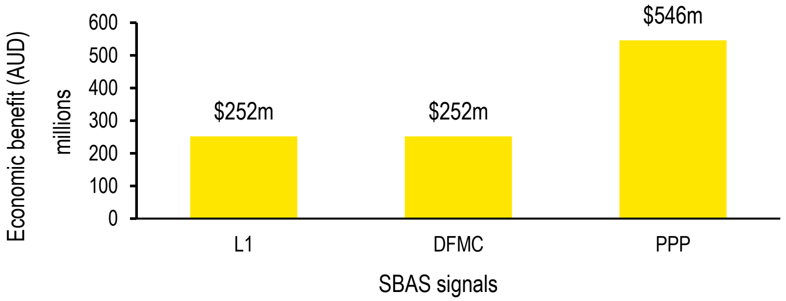


Figure MA3 – Benefits by signal type (30-year, AUD)



12. Maritime sector

12.1 Sector description

The maritime sector is broad and plays a vitally important role in both the Australian and New Zealand economies. A recent report for the Australian Shipowners Association estimated that Australia has the fifth largest shipping task in the world[206]. At a basic level, the sector covers commercial ocean and coastal shipping (including the cruise sector), stevedoring[207], port and water transport operations, harbour master operations, hydrographic surveying, fishing, marine construction, and marine activities associated with geophysics, oil, and gas extraction[208].

For the purposes of this Chapter, the maritime sector is defined by a narrower set of activities including commercial shipping, marine construction, offshore research, cruise, commercial port operations and general harbour management. These activities then take place, or result in supporting activity, in a range of different maritime environments.

To aid with presentation of the findings of this Chapter the following definitions have been used to group activities (and economic benefits):

On port

For the purposes of this assessment, on port activity is defined as all commercial activity that takes place on the port apron (wharves and associated landside footprint). Benefits in this category relate to the management of cargo on the shore.

In harbour

A harbour tends to be a physical area where water meets land and results in a sheltered bay[209]. This term refers to all maritime activity that takes place in a harbour environment.

At sea

For the purposes of this assessment, all activity that is seaward of the in harbour definition is considered to be at sea.

Optimising maritime operations through greater utilisation of positioning technology can have many economic benefits that are discussed later in this Chapter.

12.2 Use of positioning technology

The use of positioning technology in the maritime sector varies considerably depending on the application and environment.

12.2.1 On port

The use and sophistication of positioning technology in the on port environment is closely correlated to the level of automation that exists within a given port operation. In general, the larger the operation, the higher the need for positioning technology and the higher the expectations around positioning performance.

For process automation of container handling equipment (in a container terminal) differential corrected GNSS data is required at a minimum. Currently this is achieved by installing a base station and sending differential corrections is to the rovers (e.g. moving port equipment with a receiver such as cranes and straddle carriers)[210].

SBAS signals can potentially assist in reducing the need for ground-based infrastructure (such as base stations) or can be used as a viable redundancy for existing technology.

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[206] PwC (2015) The economic contribution of the Australian maritime industry. Retrieved from: https://www.mial.com.au/our-work/the-maritime-sector-contributed-over-20-billion-to-the-australian-economy
[207] A waterfront manual labourer who is involved in loading and unloading ships.
[208] Statistics NZ (2016) New Zealand's marine economy: 2007-13. Retrieved from: https://unstats.un.org/unsd/class/intercop/expertgroup/2017/AC340-Bk9.PDF
[209] Barnes, M (2013) Port, harbour or terminal: What's the difference? Retrieved from: http://www.portinfo.co.uk/port-information/our-blog/247-what-s-the-difference-between-a-port-harbour-and-terminal
[210] Information provided by a Demonstrator Project.

12.2.2 In harbour and at sea

Requirements for safety of navigation within the maritime sector are based on the standards set by the International Maritime Organisation (IMO) and revolve around positioning accuracy, integrity, redundancy, and service levels. Requirements vary according to the type of maritime activity involved.

A summary of the general requirements across the different activities is provided in Table MA1[211]. These values are all provided at a 95 percent confidence interval.

Please note that 'Time to alarm' refers to the specified time limit within which a system should be able to warn the user that it should not be used for navigation. 'Alert limit' is the magnitude of positioning error permitted before a warning is issued. Both terms are subsets of signal integrity.

Table MA1 – Maritime positioning requirements

Activity	Horizontal accuracy	Vertical accuracy	Alert limit	Time to alarm
General maritime navigation	10m	-	25m	10s
Tugs	1m	-	2.5m	10s
Oceanography	10m	10m	25m	10s
Construction works	10cm	10cm	25cm	10s
Container/cargo management	1m	1m	2.5m	10s

In addition to these general requirements, it is worth focussing on the distinct, but related requirements of Harbour Masters.

The general function of a Harbour Master is often stipulated in legislation but can be summarised as having powers to direct and control the safe movement, entry and exit of vessels within defined port areas. Safe navigation in the port area is maintained through an ongoing process of risk evaluation and mitigation of which pilotage (the process of piloting a vessel), navigation, and hydrographic survey are key components.

In the case of pilotage and navigation, pilots typically board vessels with portable pilot units (PPUs)[212], which are tools to assist the pilot in the safe navigation of the vessel. PPUs require continuously available GNSS positioning information at an accuracy suitable for navigation of large vessels in constricted water ways.

In the case of hydrographic surveying, land-based augmentation is necessary to achieve the accuracy required for producing nautical charts. Remote reception of land-based augmentation uses the cellular phone network. This can be unreliable and lacks redundancy in real-time.

The SBAS signals can potentially offer better performance than these regulatory minimums and operational realities, which can enable a range of benefits to ultimately accrue to various parties.

12.3 Demonstrator Project descriptions

Three Demonstrator Projects were commissioned to investigate the potential benefits of SBAS to the maritime sector. Two Demonstrator Projects focussed on benefits to a specific geographical area while one Demonstrator Project provided signal performance data across a very wide geographical area. A depiction of this geographical coverage is provided in Figure MA4. Further details of these Demonstrator Projects are contained in Table MA2.

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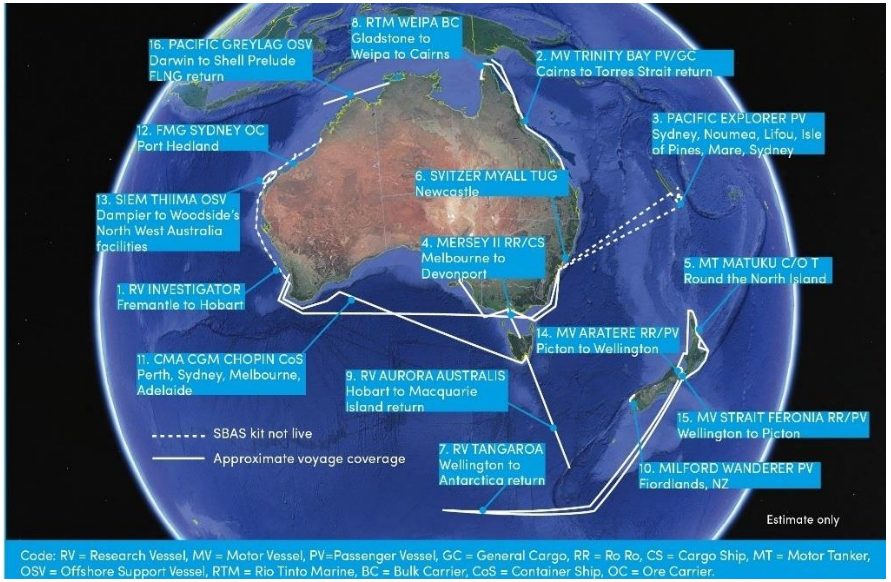
[211] IMO (2002) Revised maritime policy and requirements for a future global navigation satellite system (GNSS) Resolution A.915(22), London, United Kingdom, January 22, 2002. Retrieved from: https://puc.overheid.nl/nsi/doc/PUC_1412_14/1/

[212] A PPU displays position, speed, heading and rate of turn information to provide the pilot with a predicated location of the vessel at a future time relative to other traffic and navigation hazards in the harbour, and on an electronic chart updated by hydrographic survey.

Figure MA4 – Geographic coverage of one of the maritime Demonstrator Projects



Code: RV = Research Vessel, MV = Motor Vessel, PV=Passenger Vessel, GC = General Cargo, RR = Ro Ro, CS = Cargo Ship, MT = Motor Tanker, OSV = Offshore Support Vessel, RTM = Rio Tinto Marine, BC = Bulk Carrier, CoS = Container Ship, OC = Ore Carrier.

Table MA2 – Maritime sector project descriptions

Demonstrator project	Description	Signals tested
Acoustic Imaging/Port Authority of NSW (PANSW)	Exploring the ability to potentially improve efficiency of PANSW management of Sydney Harbour vessel traffic through the integration of SBAS into hydrographic survey and pilotage navigation activities.	L1, DFMC, PPP
Identec Solutions	Testing whether SBAS can be used as a regional replacement for, or redundancy of DGNSS in port environments. Testing whether SBAS can support improved transport efficiency in the terminal environment.	L1, DFMC, PPP
Maritime Industry Australia Limited (MIAL)	Testing the potential benefits of SBAS in a range of maritime sector areas across Australia and New Zealand, including commercial, cruise, research, offshore oil and gas, and marine construction.	L1, DFMC, PPP

12.4 Anticipated benefits

A benefits mapping exercise was undertaken with each Demonstrator Project to identify how the benefits of the SBAS signals could flow through to operational changes in the future. This then led to the identification of the following potential operational benefits.

12.4.1 On port

Reduction in misplaced containers

Many container terminals currently employ automated or semi-automated technology to enhance on port productivity. Most notably, this applies to types of equipment used in container movements (such as straddle carriers).

A straddle carrier is a freight carrying vehicle that carries its load underneath by straddling it, rather than carrying it on top like a conventional truck. The advantage of the straddle carrier is its ability to load and unload without the assistance of cranes or forklifts.

On occasion, containers within the onshore port environment may not be placed in accordance with a predetermined container management plan. Whilst in certain instances this mistake will be attributable to operators not following procedure or plans, a portion of these misplaced containers are due to errors resulting from reduced positioning performance during blackout events (i.e. when on-site positioning systems go down and more manual processes must be employed)[213].

Misplacement of containers can occur in many ways and include instances such as placing containers onto an incorrect storage stack, loading containers onto an incorrect freight truck due to incorrect parking bay information, and picking up an 'incorrect' container, which is usually directly adjacent to the correct container.

It is expected that the SBAS signals may provide redundancy in periods when there are blackout events. This continuity of service means that a container terminal/port operator can achieve the benefits of automated and semi-automated port operations a greater proportion of the time.

Enhanced port planning

Most container ports currently operate sophisticated workflow planning systems to manage container movements across the yard. Broadly speaking,

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[213] A Demonstrator Project confirmed that blackouts can be due to hardware, software, or server issues, or because of port-wide power/internet outages.

software is used to track an individual straddle carrier within a port and direct them to pick up and drop off specific containers. Once a straddle carrier drops off a container, complex algorithms are used to calculate its next pick up target, based on maximising effectiveness and efficiency of movement. In simple terms, this means picking up the container closest to the straddle carrier rather than on another side of the port. The incremental operational efficiencies that can be gained from this improved workflow management can result in significant productivity gains over a long period of time.

The ability of port planning software to work is largely dependent on the ability to track the relative positioning of straddle carriers and containers. During blackout events[214], operational instructions passed on by the software system are marked as untrustworthy and there is a reduction/cessation of the transmission of real-time information to crane operators. This ultimately leads to reduced efficiency as straddle carriers cease to follow optimal routes to pick up and drop off containers.

Just as the SBAS signals can provide redundant positioning information for the movement of containers, they can also act as a backup system that maintains positioning accuracy during blackout events, thereby enabling a continuation of efficiencies enabled by automated and semi-automated practices.

Reduction in health and safety risks on port

There are a range of day-to-day tasks associated with the operation of a container port which expose workers to hazards (for example falling containers and objects, overhead cranes, and slippage areas). This risk can be heightened when automated and semi-automated port equipment is on-site as their ability to react to the presence of people can be variable.

It is expected that the SBAS signals will help provide greater redundancy to automated and semi-automated port operations. Put simply, the transition to more automated port environments can then reduce the number of people on-site and with fewer people on-site there is less opportunity for physical workplace injuries and incidents.

12.4.2 In harbour

Under keel clearance management[215]

The SBAS signals offer the ability for the dynamic position of a vessel to be known in real-time with a higher degree of accuracy. Knowing how much a vessel is squatting[216] will allow the squat (and therefore under keel clearance (UKC)) to be managed by controlling the speed of the vessel. This benefit is only possible to realise where UKC is actively managed and there is a high degree of confidence in the vertical positioning of the vessel (particularly in relation to the sea floor).

This benefit can enable more efficient cargo movements either in the form of maximising the draught of the vessel that is sailing, or by widening the tidal window for each tide thereby enabling one or more additional vessels to sail on that tide. This ultimately can result in shipping cost savings and greater throughput depending on how the improved knowledge of UKC is utilised and provided volumes are not constrained elsewhere in the supply chain.

A depiction of UKC is shown in Figure MA5[217].

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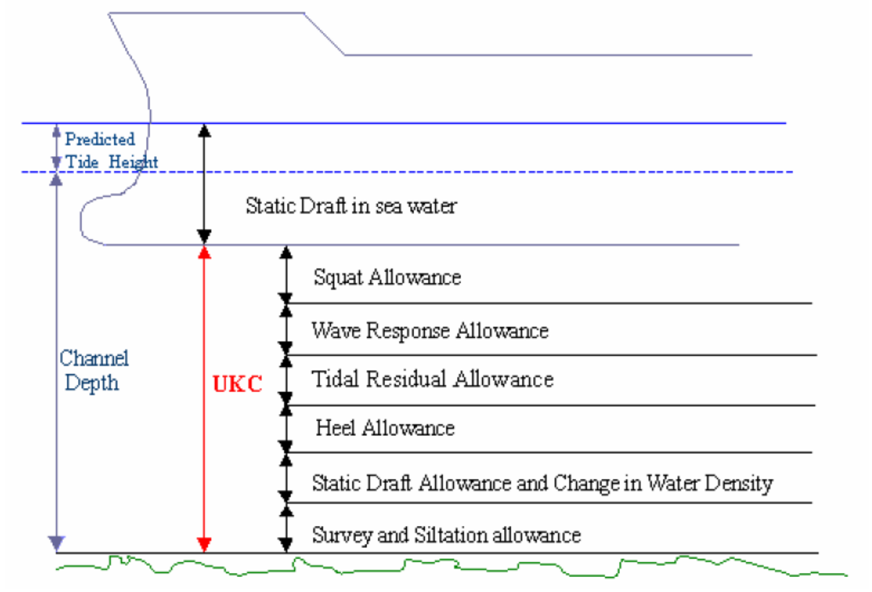
[214] Discussion with the sector suggests that blackout events can occur across one percent of all operational hours. For the purposes of this economic analysis, focus is on base station failures causing terminal-wide outages with regards to positioning data.

[215] The description of this benefit has been adapted from the relevant Demonstrator Project – including Project Report content and the outcomes of sector workshops.

[216] The squat effect is the hydrodynamic phenomenon by which a vessel moving quickly through shallow water creates an area of lowered pressure that causes the vessel to be closer to the seabed than would otherwise be expected. Transport Safety Board of Canada (2000) Marine Investigation Report: Striking of the bulk carrier Tecam Sea by the Bulk Carrier Federal Fuji in the Port of Sorel, Quebec 27 April 2000. Retrieved from: https://web.archive.org/web/20051123014725/http://www.tsb.gc.ca/en/reports/marine/2000/M00L0039/M00L0039.asp.

[217] Obrien, T and O'Brien, P (2004) UKC management through dynamic underkeel clearance systems. Retrieved from: http://www.omcinternational.com/wp-content/uploads/2015/02/UKC-Management-through-Dynamic-Underkeel-Clearance-Systems-Germany.pdf

Figure MA5: Factors that determine UKC



Increased vessel capacity in harbour[218]

For all commercial vessels that enter confined waters, it is commonplace (and often a legislative requirement[219]) for pilots to board vessels and work with the bridge team to safely manoeuvre and navigate the vessel. Pilots typically board vessels with PPUs which consider a suite of information including vessel traffic management (information to vessels), vessel automated identification systems (AIS) (relative location of other vessels), ocean currents, tides, weather, most recently charted depths, and other information specific to a particular location.

Key information required from PPUs is not always available at the required level of accuracy to provide a pilot with situational awareness without input of the pilot's visual awareness. Therefore, it is more difficult to manoeuvre vessels into, out of, and inside the harbour in low visibility and this is most affected by lack of daylight hours and adverse weather conditions. There is an opportunity to improve productivity using SBAS to increase vessel movements inside a harbour by meeting the required air draft beneath bridges, the passage through narrow restrictions, and the clearance above the seafloor.

With projected improvements in accuracy, availability, and integrity afforded by the SBAS signals, a pilot can place increased reliance on the predictions from PPUs to inform awareness of upcoming navigation manoeuvres. This will reduce dwell times resulting from low visibility, clearance in restricted channels, and clearance below bridges on higher tide and above the sea floor. Similarly, integrity, and availability of spatial data at sufficient accuracy will help decrease dwell times of vessels due to improved understanding of height and depth constraints.

Real-time hydrographic surveying

Undertaking risk assessments and regular hydrographic surveys is critical in dynamic harbour environments where large vessels manoeuvre. Charts produced must be thoroughly validated for accuracy prior to charting and distribution as electronic charts for use in PPUs. This activity is time and resource intensive with current methods causing a delay between acquisition of hydrographic data and charting.

A reliable and sufficiently accurate source of space augmentation will increase rate at which the very latest real-time hydrographic data can be acquired and validated for charting constricted high traffic areas of the harbour such as berths, beneath bridges, and around infrastructure.

Current methods of hydrographic survey and nautical charting rely on the vessel's consistent reception of the cellular phone network. This is rarely the case on a rolling, pitching, yawing, and heaving vessel. It is anticipated that the SBAS signals will provide the availability required at the required accuracy to reduce the reliance on the mobile phone network, increase the area of operability to the extents of the SBAS coverage. This will boost the rate at which the port is able to provide the latest electronic charts to the pilot.

Lower risk real-time navigation and pilotage

To promote the safe movement of piloted vessels in confined waters, buffer zones are employed when navigating and planning a piloted vessel's course. The size and nature of these buffer zones are determined by vessel size, localised environmental conditions, and the performance of positioning.

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[218] The description of this benefit – as well as the real-time hydrographic surveying and lower risk real-time navigation and pilotage benefit – has been adapted from the relevant Demonstrator Project.

[219] In Sydney Harbour for instance, pilotage is compulsory for all vessels 30m and over in length unless specifically exempt under Section 75 of the Marine Safety Act 1998.

Inefficient large buffer zones have the practical effect of decreasing the capacity of a harbour to accommodate vessel movements.

The combination of real-time hydrographic surveying and more effective utilisation of PPUs, coupled with existing processes, means that vessels can potentially reduce their total propagated spatial uncertainty and directly impact the size of any buffer zone surrounding a vessel. In practice, this can result in increased capacity of a given waterway.

Improved health and safety outcomes (pilots)

In the short term, SBAS should improve situational awareness for pilots by reducing their reliance upon their visual awareness. This should have improved health outcomes for pilots in a high-stress, high-risk environment. Ultimately pilots may eventually not need to physically board vessels.

Safety benefits for harbour users

It is expected that there would be the potential for fewer accidents (and near misses) as pilots are responding to information in real-time. This can lessen the likelihood of death and injury associated with accidents as well as reducing financial replacement costs and other disruption costs associated with responding to maritime incidents.

12.4.3 At sea

Savings in the cost of subscription services

Vessels enabled with dynamic positioning (DP) can automatically maintain position and/or heading (fixed location, relative location, or predetermined track) by means of thruster force. This is partially achieved by incorporating inputs from various sensors (including high-precision GNSS) to the ship's control system. DP vessels are used extensively in offshore oil and gas operations and elsewhere[220].

DP vessels often have access to a range of positioning subscription services offering sub-metre through to centimetre-level accuracy. Depending on the criticality of the task, some DP vessels can have multiple subscriptions (for example offshore activity where vessels can have multiple sets of hardware) as they have a heightened need for access to accurate and reliable positioning.

It is anticipated that PPP could be utilised by DP vessels, which could subsequently reduce costs associated with positioning subscription services.

Savings in replacing Australian maritime DGPS network[221]

The Australian Maritime Safety Authority (AMSA) provides a DGPS network for augmentation of GPS signals for maritime navigation. The most important aspect of maritime DGPS is integrity monitoring which provides vessels with an indication of instances where satellite reliability is compromised.

AMSA's DGPS network has been running for almost 15 years and is nearing its end of life. AMSA is anticipating a need to keep this system functioning in the short-term but then faces an important asset replacement decision. AMSA believes there could be the opportunity to replace DGPS with SBAS that would have potential benefits in the form of avoided capital (and operating costs) in the long-term.

It is also worth noting that there is an international precedent for this transition, with the United States Coast Guard making a decision to discontinue their DGPS systems[222]. Moreover, the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) is also considering using SBAS. In the short term, IALA is considering SBAS as an alternative/supplementary source of corrections for the current DGNSS system.

In the longer term, SBAS could provide a maritime SoL service similar to aviation and be used to its full potential (almost all marine receivers can be SBAS-enabled and could benefit from such service)[223].

Please note that New Zealand does not have a radio-based DGPS network like Australia and hence the replacement of New Zealand's DGPS network is not included in this benefit category.

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[220] Information provided by a Demonstrator Project.

[221] The description of this benefit has been adapted from information provided by a Demonstrator Project.

[222] Midgett, A. (2018) Remaining DGPS sites to be discontinued over the next 3 years. Retrieved from: http://mariners.coastguard.dodlive.mil/2018/03/23/3-23-2018-remaining-dgps-sites-to-be-discontinued-over-the-next-3-years/

[223] European Global Navigation Satellite System Agency (2018). GNS user technology report, issue 2. Retrieved from: https://www.gsa.europa.eu/system/files/reports/gnss_user_tech_report_2018.pdf

These anticipated benefits have been classified into the following benefit categories, as shown in Table MA3[224].

Table MA3 – Maritime sector benefit categorisation

Benefit	Benefit category	Quantitative?
On port		
Reduction in misplaced containers	Operating expenditure savings	Yes
Enhanced port planning	Operating expenditure savings	Yes
Reduction in health and safety risks on port	Health and safety	No
In harbour		
Under keel clearance management	Operating expenditure savings	Yes
Increased vessel capacity in harbour	Operating expenditure savings	Yes
Real-time hydrographic surveying	Operating expenditure savings	Yes
Lower risk real-time navigation and pilotage	Operating expenditure savings	Yes
Improved health and safety outcomes (pilots)	Health and safety	No
Safety benefits for harbour users	Health and safety	No
At sea		
Savings in the cost of subscription services	Operating expenditure savings	Yes
Savings in replacing Australian maritime DGPS network	Avoided capital expenditure	Yes

12.5 Positioning needs and current methods

12.5.1 On port

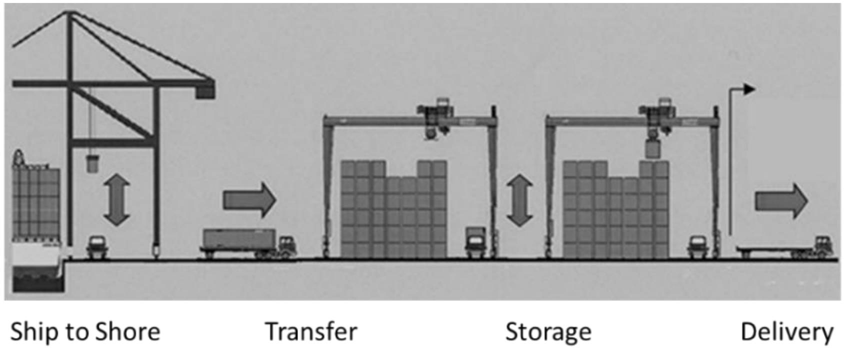
At the simplest level, the function of a container terminal is the transfer and storage of containers. Containers are offloaded, sorted, and stored in the container yard before being transferred to landside transport modes or transferred onto other container vessels. Currently DGNSS is used by the Demonstrator Project to position port vehicles.

A more detailed look at container port operations outline four key components:

- Ship to shore is the movement of containers from wharf to and from container vessels using quay cranes.
- Transfer is the movement of containers between the wharf and the storage area, using container trucks, straddle carriers, automated gantry vehicles or gantry cranes.
- Storage covers the storage and organisation of containers into large stacks, easily accessed by the wharf or gate operations.
- Receipt/delivery refers to the transfer of stored containers to the road and/or rail network or distribution to final destinations.

This operational system is further illustrated in Figure MA6.

Figure MA6: Container port operational cycle



The benefits of accurate and reliable positioning in a container port environment generally centre on two positioning applications: container tracking and port equipment tracking.

These two requirements form the basis for all on-port benefits and the following sections aim to establish the positioning needs (and current positioning methods) for each on port application.

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[224] Colour coding in Table MA3 has been used to more clearly highlight the relevant benefit categories.

Container positioning

Understanding where a container is located can minimise the risk of selecting the wrong container when transferring, storing, and delivering containers.

The minimum accuracy requirement for individual container tracking is assessed by a Demonstrator Project as being half a container width (1.2 metres) to ensure a container can adequately be identified within a container stack (horizontal and vertical accuracy) or can be accurately placed on a truck for delivery (horizontal only).

Given the fast-paced nature of on-port operations and the handling of multiple containers at any given time, it is also important to ensure signal availability, with a Demonstrator Project noting that the aforementioned accuracy levels must be available at least 99.7 percent of the time.

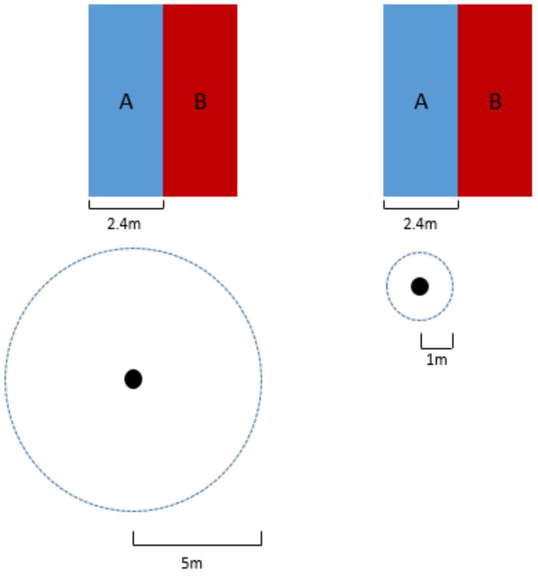
Port equipment positioning

Understanding where port equipment (including straddle carriers) are at all times can enable better port planning.

An assumption for this analysis is that tracking of port equipment within a port environment, such as straddle carriers, must be at a similar resolution to container tracking requirements (i.e. around a metre horizontally). The rationale for this assumption is that attaining such a level of accuracy will enable users to ascertain where a vehicle is in relation to a given container. In other words, a user can accurately determine that a straddle carrier is in front of one container and not the container directly adjacent to it.

Figure MA7 diagrammatically represents how the low spatial resolution afforded by standalone GNSS with accuracy of ± 5 metres can make it difficult to identify the position of a vehicle in relation to a specific container (container A and not container B), whereas sub-metre accuracy enabled by SBAS provides greater certainty.

Figure MA7 – Depiction of how a ± 5m positioning accuracy (and associated buffer) can make it difficult to identify vehicle proximity to a specific container



Metre-level positioning is also necessary for the tracking of freight vehicles. Based on discussion with a Demonstrator Project, it is understood that upon arrival at a port, a freight truck drives to a loading area where it parks in one of many parking bays. These parking bays have unique identifiers which are used to instruct straddle carrier drivers.

Low spatial resolution increases the risk of human errors whereby workers may park vehicles in incorrect parking bays, leading to situations where straddle carrier drivers are instructed to take a container to the wrong loading bay.

Austroads guidance[225] has been used as a comparable proxy to establish that lane-level positioning (or metre-level positioning horizontally) is sufficient to minimise the risk of misallocation of containers.

Importantly, whilst port vehicle tracking for the purposes of workflow management largely has a diminishing return beyond 1.2 metres, the sub-metre capability of SBAS has potential to unlock additional benefits around

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[225] Austroads (2013) Austroads research report - Vehicle positioning for C-ITS in Australia (background document). Retrieved from https://www.onlinepublications.austroads.com.au/items/AP-R431-13,

connected intelligent transport systems, such as collision avoidance and lane departure alerts.

12.5.2 In harbour

Positioning is essential for safe and efficient navigation within harbour environments. All harbours across Australia and New Zealand (that have dynamic maritime environments) have access to some form of positioning.

High-accuracy positioning can enable enhanced measurement of heading and velocity, which can help improve the bridge team's[226] situational awareness and ability to judge a dynamically changing situation. This means that large vessels can be manoeuvred and berthed safely in confined areas, with minimal risk of damage to port infrastructure.

High-accuracy positioning also enables the bridge team to manoeuvre and navigate vessels more accurately in relation to hazards.

Some ports however have more sophisticated positioning technology depending on factors such as length of channel entrance, hydrographic issues, climatic issues, size, and frequency of vessels passing through and financial performance required[227]. Specific examples of these requirements are provided throughout the remainder of this sub-section.

Under keel clearance management

UKC management systems utilise real-time tide and wave measurements taken prior to transit to determine the minimum safe UKC along the complete transit from berth to deep water. An example of the factors that go into UKC management systems is provided in Figure MA5.

Typically, measurements of vessel motions require at least 15 centimetres of vertical accuracy[228].

Augmented GNSS is often used to validate UKC systems when they are installed. Use of the SBAS signals can aid with the validation and calibration activities. There is potential for PPP to be used in the future to more actively manage UKC in real-time as well as being used for planning[229].

Pilotage and navigation

As noted earlier, for all commercial vessels that enter into confined waters, it is commonplace (and often a legislative requirement) for pilots to board vessels and work with the bridge team to safely manoeuvre and navigate the vessel.

PPUs require continuously available positioning information of high integrity and at an accuracy suitable for navigation of large vessels in constricted water ways. In practice this does not mean knowing the position of the GNSS receiver to highest accuracy but using the information to provide the pilot with critical heading, velocity, and rate of turn for all parts of the vessel's hull relative to surrounding potential navigation hazards.

Some ports currently deploy PPUs that use GNSS aiding only resulting in heading, velocity, and rate of turn that is inconsistent in terms of availability and integrity. The SBAS signals stand to benefit the key issues – those of supplying pilots with uniformly available aiding of integrity and suitable accuracy for critical navigation manoeuvres of increasingly large vessels in ports and harbour.

Hydrographic surveying

Hydrographic surveyors map the seafloor at high resolution and spatial accuracy for the purpose of creating nautical charts. A nautical chart represents hydrographic data, providing harbour users with information on water depths, coast lines, tide predictions, hazards to navigation such as submerged objects both geological and anthropogenic, and navigational aids. Charts are used by all harbour users including pilots and the general public.

In a busy harbour, factors affecting the seafloor can include environmental (weather events, tides, geological and oceanographic events) and anthropogenic (human and man-made structural impacts such as clearance below bridges on high water or clearance to dredge depth of channel on low water or submerged hazards). Changes in the seafloor directly impact navigation risk for all harbour users necessitating hydrographic mapping as frequently as resources allow. In an instance where hydrographic information

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[226] This refers to the Captain and supporting officers who direct operations.
[227] AMSA (2018) 'Precise positioning technology for Australia's maritime industry'. Memo for project team.
[228] Accuracy expected at 95 percent confidence interval. The precise level of accuracy will differ depending on UKC management system employed.
[229] Discussions with FrontierSI project team.

is unclear[230], port authorities impose restrictions on vessel movement and throughput to minimise the risk of adverse events occurring.

Many ports currently employ land-based augmentation (such as continuously operating reference stations (CORS) networks) to achieve required accuracy. CORS is most often transmitted via the cellular phone network, reception of which is difficult from a moving, rolling, pitching, yawing, and heaving vessel. SBAS can increase the throughput of hydrographic survey to nautical chart production.

12.5.3 At sea

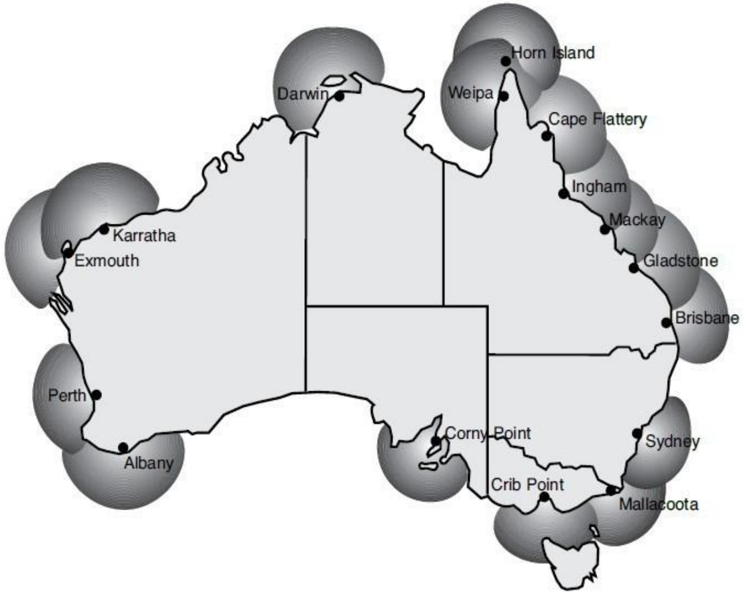
The specific positioning requirements for at sea operations are often unique to the activity being undertaken. For example, a vessel steaming on the high seas removed from any hazards will have a lower level requirement for positioning than a vessel undertaking research activities.

As noted earlier, DP vessels subscribe to signal positioning services offering sub-metre through to centimetre level accuracy. It was noted by a Demonstrator Project that 15 centimetres horizontal and vertical would be sufficient for the purposes of this assessment.

Additionally, it is noted that AMSA maintains a network of 16 DGPS base stations around the Australian coastline to ensure mariners have more accurate and reliable data from GNSS for at sea operations. These base stations provide free-to-air accuracy and integrity data for GNSS signals via radio. Figure MA8 provides an overview of these stations[231].

AMSA's DGPS network has been operational since the mid-1990s and is used by many subsectors of Australia's maritime industry. However, the existing DGPS network is limited in range[232] and does not provide coverage over all coastal waters. While it can provide positioning accuracy better than 10 metres at 95 percent confidence[233], it has been mentioned through one of the Demonstrator Projects that there is increasing demand for even more accuracy.

Figure MA8 – AMSA DGPS stations



12.6 Sector benefits

The following sections detail the benefits of SBAS relative to the status quo, describe the anticipated economic impact and estimate how benefits are attributed across the three signals.

12.6.1 Signal attribution

Table MA4 contains details of the expected performance of the SBAS signals within the maritime sector. As mentioned throughout this Chapter, when it comes to positioning requirements, some benefits are contingent on certain

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[230] For example, identification of possible new hazards: submerged or on seafloor, or onshore, or under a bridge in a constricted waterway.

[231] AMSA (2018) Australia's differential global positioning system. Retrieved from: https://www.amsa.gov.au/safety-navigation/navigation-systems/australias-differential-global-positioning-system

[232] As the distance between the user and the DGPS station increases, the signal from the satellite is forced to take different paths to each location. Due to atmospheric variations, the user's receiver experiences a different delay compared to the reference station. The greater the separation, the more difficult it becomes to correct errors. As a result, the further the user is from the reference station, the more inaccurate the navigational data can become. AMSA (2018) Australia's differential global positioning system. Retrieved from: https://www.amsa.gov.au/safety-navigation/navigation-systems/australias-differential-global-positioning-system

accuracy thresholds being met, whilst other benefits improve as positioning accuracy improves.

It is noted that the broader IMO requirements noted in Table MA1 are also expected to be met through an operational SBAS[233]. Relatedly, it is worth clarifying that PPP convergence is not an issue in the maritime environment, because receivers are turned on once and they stay on. Hence, there is no need for re-convergence.

These indicative test results have been provided by FrontierSI as representative results of the testing carried out by the SBAS Demonstrator Project in this sector. Values are presented at a 95 percent confidence interval.

Where deviations exist, DFMC SBAS results are expected to be similar to SBAS L1 in an operational system. The testing was carried out in open sky environments with professional equipment.

For the avoidance of doubt, an indication of whether a given benefit requires horizontal or vertical positioning performance is provided in Table MA4. In most cases horizontal positioning is required, although UKC management, some on port activities, hydrographic surveying, and subscription services benefits also benefit from vertical positioning information.

Table MA4 – Maritime sector signal attribution

Signal	Maritime sector test results				
	Expected horizontal performance (m)		Expected vertical performance (m)		
L1	0.9		1.9		
DFMC	1.4		3.8		
PPP	0.1		0.2		
Quantitative benefits					
Reduction in misplaced containers	Sub-metre (horizontal and vertical)	100%	100%	90%	Expected that the hardware costs for PPP would provide slightly less uptake
Enhanced port planning	Sub-metre (horizontal)	100%	100%	90%	Expected that the hardware costs for PPP would provide slightly less uptake
Under keel clearance management	10-15cm (vertical)	0%	0%	100%	Sub 15cm required meaning PPP suitable
Increased vessel capacity in harbour	Horizontal and vertical	50%	50%	100%	PPP is most suitable due to accuracy expectations
Real-time hydrographic surveying	Various (horizontal and vertical)	0%	0%	100%	Only PPP is suitable due to accuracy requirements
Lower risk real-time navigation and pilotage	Horizontal and vertical	50%	50%	100%	PPP is most suitable due to accuracy expectations
Savings in the cost of subscription services	10-15cm (horizontal and vertical)	0%	0%	100%	Only PPP is suitable due to accuracy requirements
Savings in replacing Australian maritime DGPS network	Sub-metre (horizontal)	100%	100%	0%	Requires maritime integrity
Qualitative benefits					
Reduction in health and safety risks on port	Sub-metre	✓	✓	✓	Similar level of performance required to other port benefits
Improved health and safety outcomes (pilots)	Various	✓	✓	✓	
Safety benefits for harbour users	Various	✓	✓	✓	

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[233] Segura, D. et al. (2019) Assessment of EGNOS availability, continuity and coverage for maritime applications. Proceedings of European Navigation Conference, Warsaw, 9-12 April 2019.

12.6.2 Uptake rate

Uptake rates for each quantifiable benefit have been based on a uniform assumption for the maritime sector that uptake is linear over a five-year period from the point where the SBAS signals are operational. These assumptions have been made and confirmed in discussion with all the various Demonstrator Projects[234].

While the precise uptake rates will differ by sub-sector and individual operators within the sector, this uniform assumption was validated through specific discussion. For example:

- For UKC benefits, discussion with a Demonstrator Project confirmed the assumption that once a port decides to introduce a managed UKC system they could start to receive the benefit quickly (within six months). However, it can often take many years to make this decision and to implement.
- For DGPS, a sector participant noted that vessels would likely continue to upgrade receivers between now and 2024 and that a five-year lead in time is reasonable before all receivers are SBAS capable. This is also a reasonable amount of time to decide about the future viability of the DGPS network and allow appropriate supporting regulations to be developed.
- For all in harbour activities, a Demonstrator Project confirmed the view that the full suite of benefits would likely be accruing by year five as many of the vessels noted above would also be present in an in harbour environment.

In many instances, the supporting hardware, software, and operating processes are already in place to accommodate the SBAS signals and so this would require a relatively straightforward integration process[235].

12.6.3 Quantitative benefits – on port

Quantitative benefits relating to the implementation of an operational SBAS will predominantly accrue to automated and semi-automated port environments. All references to ports in the proceeding sections of this Chapter have this caveat attached.

12.6.3.1 Reduction in misplaced containers

By affording a degree of redundancy to the positioning system used in port environments (particularly container terminals), SBAS is anticipated to increase efficiency experienced during blackout events, which in turn will help avoid 16,000 misplaced containers over a 30-year period. This is anticipated to generate PV$28m in operating savings for ports over a 30-year period.

A Demonstrator Project confirmed that blackouts can be due to hardware, software, or server issues, or because of port-wide utility outages. For the purposes of this economic analysis, the focus is on base station failures causing terminal-wide outages with regards to positioning data.

The impact of a blackout depends on its duration. Generally, all staff have clear instructions on what to do for the 30–45-minute period immediately after a blackout. Therefore, whilst the margin of error increases, due to increased human judgement, it only increases significantly after 45 minutes.

Discussion with the sector confirmed that of the total containers handled within the sector per year, which stands at approximately nine million twenty-foot equivalent units (TEUs) across Australia and New Zealand for 2016, roughly 1.6 percent are handled during blackout events. Over a 30-year period, this amounts to a little over six and a half million TEUs handled during blackout events, if a container growth rate of two percent per annum is applied.

It is then assumed that 0.26 percent of these containers are misplaced (based on approximations by sector experts around the number of containers misplaced each month).

Following discussion with a Demonstrator Project it is assumed that the greater redundancy in the port positioning system enabled by SBAS will help avoid 95 percent of these misplaced containers during blackout events.

Operational savings reflect reduced labour costs required to (re)locate misplaced containers. It is assumed that for each misplaced container an

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[234] In the case of one Demonstrator Project, this included six workshops across Australia and New Zealand engaging maritime operators and other stakeholders to discuss the capabilities of the SBAS signals across a range of user types.

[235] This is in alignment with some other sector Chapters (for example transport and agriculture) where some of the economic benefits are much more reliant on emerging technology and the creation of new systems, networks and processes.

average worker is required to spend twice the amount of time handling it, therefore accruing roughly twice the per-container operational cost.

The anticipated total number of misplaced containers avoided by utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table MA5.

Table MA5 - Savings through reduced incidence of misplaced containers (30-year calculation)

Factor	Value	Notes
Total number of containers handled during blackout events	6.43m	Total Australia and New Zealand container count over 30 years. Assumed 1.6% of total container throughput is handled during a blackout event.
Number of misplaced containers during a blackout event	16,800	Total misplaced containers based on 0.26% of containers being misplaced during blackout events.
Number of misplaced containers avoided through greater redundancy	15,200	95% of containers misplaced are assumed to be avoided due to SBAS signals. Adjusted for uptake (linear, five-year uptake rate).
Gross value	$76m	Average wage (AUD 32 per hour) for port employee used as value proxy. Total time taken to locate misplaced container derived from Demonstrator Project information.
Present value	$28m	Discounted at 6.5%

Note: Totals may not sum due to rounding

12.6.3.2 Enhanced port planning

The potential benefits generated from increasing the efficiency associated with port planning during blackouts amounts to PV$205m over a 30-year period across the maritime sector.

In arriving at this value, total operational hours for ports across Australia and New Zealand has been established on a per annum basis, of which total blackout operational hours were derived based on discussion with sector experts. This is assumed to be the same as in the reduction in misplaced containers benefit (1.6 percent).

For modelling purposes, it has been assumed that inefficient port planning during blackout scenarios will lead to an additional six minutes per hour for tasks to be completed.

This efficiency premium is then applied to all port site workers, as well as to the operating costs of straddle carriers, on automated and semi-automated ports.

To derive the relevant value calculations, an interrogation of various annual reports coupled with conversations with the sector determined that the following values are appropriate[236]:

- Average labour cost per hour of $32 (excl. overheads)
- Operating cost of relevant straddle carriers is estimated to be $107 per hour, per port. This has been estimated based on fuel cost only due to data limitations.

An effectiveness discount of five percent (95 percent effectiveness rate) was then applied to these results in acknowledgement of the fact that having SBAS will not reduce these inefficiencies.

The anticipated savings through enhanced port planning by utilisation of the SBAS signals have been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table MA6.

Table MA6 - Savings through enhanced port planning (30-year calculation)

Factor	Value	Notes
Total hours of port operation	3.8m	Assumed 360 days per year, 24 hours a day port operation. Cumulative Australia and New Zealand value over 30 years.
Total blackout hours	60,700	Total port hours of operation across Australia and New Zealand multiplied by a factor of 1.6% (the proportion of containers handled during blackout events).

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[236] Port Authority New South Wales (2018) Annual report. Retrieved from: https://www.portauthoritynsw.com.au/media/3366/pa_064_ar_18_wcag_final-nov-2018.pdf; Ports of Auckland (2018) Annual report. Retrieved from: http://www.poal.co.nz/media-publications/resultsandreviews/2018%20Annual%20Report-FINAL.pdf

Factor	Value	Notes
Additional labour cost during blackouts	$610m	This cost is reflective of the additional labour cost and the additional cost of operating straddle carriers.
Operating expenditure savings due to SBAS	$580m	6 min inefficiency discount while ports re-establish planning processes through a blackout 95% discount to attribute to SBAS
Gross value of savings	$550m	Adjusted for uptake (linear, five-year uptake rate).
Present value	$205m	Discounted at 6.5%

Note: Totals may not sum due to rounding

12.6.4 Qualitative benefits – on port

12.6.4.1 Reduction in health and safety risks on port

There are a range of day-to-day administrative tasks associated with the operation of a container port which requires workers to undertake activities in hazardous environments. These tasks include, but are not limited to:

- Manually checking the integrity of containers
- Manually checking the integrity of container stacks
- Manually guiding straddle carriers
- Driving straddle carriers
- Servicing straddle carriers.

According to industry experts, in order to reduce health and safety risks an exclusion zone is placed around each clerk (or port worker) when they are in live operational areas carrying out the aforementioned tasks, which restricts vehicles and plant to move in close proximity. This can reduce the efficiency of operations on port, particularly when multiplied over a longer period.

The enhanced redundancy afforded by the SBAS signals enables automated systems to be put in place to manage straddle carrier movements around port terminals and for automated checks and balances to be placed to assess the health of straddle carriers and containers. In addition to the potential productivity gains, this automation of operational processes stands to enhance health and safety outcomes by reducing the number of clerks, and the amount of time required by clerks, to be spent in live operational areas which contain numerous hazardous risks such as falling containers, overhead cranes, falling objects, and slippage areas.

Moreover, having fewer people on-site, means there are fewer exclusion zones for vehicles and plant to manoeuvre, which can potentially support the continuation of operational efficiencies enabled by automated and semi-automated port equipment.

12.6.5 Quantitative benefits – in harbour

12.6.5.1 Under keel clearance management

Over a 30-year assessment period, it is anticipated that a total of PV$97m of productivity benefits is possible for a single Australian port from the utilisation of PPP in support of an enhanced UKC management system.

It is critical at the outset to note that these UKC benefits are estimated based on inputs from a small sub-set of harbour environments and represent an inherently narrow consideration of potential benefits. Unique operating and contractual arrangements (as well as commercial confidentiality) mean that scaling has not been possible.

Up to 10 additional harbours/ports across Australia and New Zealand have been identified by a Demonstrator Project as potentially benefitting from better UKC management using PPP. Moreover, it is noted by a Demonstrator Project that at least 19 harbours/ports currently employ some type of UKC management – 16 in Australia and three in New Zealand.

It is also critical to acknowledge that this calculation methodology has been significantly developed by a Demonstrator Project and has benefitted from the outputs of six workshops across the maritime sector.

The deployment of an active UKC management system using PPP can result in several operational responses in a harbour environment, each of which have a different economic benefit profile and require different calculation methodologies.

From a vessel perspective, it is possible that for UKC management either of the following options may be possible:

- Widen the tidal window for each tide, which can enable an additional vessel(s) to sail on that tide, or

- Maximise the draught of the vessels that are sailing, resulting in the potential to move more cargo at a given point in time. Draught refers to the depth of a vessel while in the water. Measured as the vertical distance between the waterline and the lowest edge of the keel[237].

Discussion with the sector, in the context of a particular subset of port environments, suggested that a 90:10 split between a wider tidal window and increased draught is appropriate for this analysis.

From a cargo perspective, it is then possible to use the additional potential capacity described above to increase output (i.e. same vessel movements carrying more cargo) or improve efficiency of voyages (i.e. fewer vessels are needed to carry the same amount of cargo, or it is more cost effective to move the same amount of cargo).

For this assessment, it is assumed that cargo output is fixed and that the economic benefit is through a more productive vessel management programme.

In terms of the number of voyages that are likely to be affected from this change in operation, it is conservatively assumed that:

- For wider tidal window, additional voyages on 25 percent of neap tides and 15 percent of spring tides were seen as benefitting from the SBAS signals.
- For increased draught, an additional 10-centimetre draught is assumed for voyages on 25 percent of neap tides and 25 percent of spring tides were seen as benefitting from the SBAS signals.

Neap and spring tides refer to higher and lower than usual tides related to the gravitational pull of the moon (and the sun).

A capacity factor of 65 percent was then applied to this calculation in recognition of the fact that just because additional shipping capacity is available does not always mean that it will be filled. This factor was estimated through discussions with various sector participants.

To determine this value, it is acknowledged that every transaction that may benefit from UKC will have its own unique commercial drivers and characteristics which make generalisation of this economic benefit extremely challenging. For example, time charters, voyage charters, and free on board[238] arrangements all have different contractual structures and will generate different economic benefits. Moreover, each transaction will also involve different contractual parties which makes the beneficiary hard to define.

However, discussion with the sector determined that a productivity saving on a ‘cents per tonne’ basis[239] would be a reasonable estimate of the economies of scale savings through enhanced UKC using PPP and would apply to all volumes moved. Moreover, this improvement is assumed to be retained by Australian (and New Zealand) interests involved in the movement of the vessel and/or cargo – such as the miners, the cargo owners, etc. For the avoidance of doubt, this definition does not include vessel owners.

The anticipated productivity savings associated with the utilisation of PPP in support of an enhanced UKC management system has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table MA7.

Table MA7 – UKC benefits for one port only (30-year calculation)

Factor	Value	Notes
Total gross tonnes enabled from enhanced UKC using PPP	395m	Consists of 394m via enhanced tidal window and 1m tonnes via increased draught. 30-year cumulative total.
Total gross tonnes enabled adjusted for uptake	369m	Adjusted for uptake (linear, five-year uptake rate).
Total gross tonnes enabled – discounted for capacity	240m	65% discount factor applied in acknowledgement that not all capacity will be filled.
Total additional and business as usual tonnes shipped	Withheld	Based on a sum of current throughputs and additional throughput noted above.
Gross productivity saving	Withheld	A confidential savings per tonne carried rate has been assumed as a result of the economies of scale

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[237] Draught refers to the depth of a vessel while in the water. Measured as the vertical distance between the waterline and the lowest edge of the keel. Siene Maritime (n.d.) Glossary of Port and Shipping Terms. Retrieved from: http://www.seinemaritime.net/suports/uploads/files/Glossary%20of%20Port%20and%20Shipping%20Terms.pdf

[238] Free on board arrangements refer to contractual terms that refers to the requirement that the seller deliver goods at the seller's cost via a specific route to a destination designated by the buyer. https://www.merriam-webster.com/dictionary/free%20on%20board

[239] Please note that a specific ‘cents per tonne’ figure has been used in the modelling, but has been redacted from commercial sensitivity reasons.

Factor	Value	Notes
		gained through enhanced UKC using PPP.
Present value	$97m	Discounted at 6.5%

Note: Totals may not sum due to rounding

This quantitative assessment has focussed on the economic benefits that were raised through the Demonstrator Project and utilised information provided from participants. However, it is worth noting that the time value of money from a cargo owner being paid sooner (because they are shipping sooner) has not been contemplated but would be expected to be a material benefit.

12.6.5.2 Increased vessel capacity in harbour

Over a 30-year assessment period, it is anticipated that PV$53m of economic benefits would accrue to the port operators of Sydney Harbour in the form of increased vessel capacity.

Each year, on as many as 46 days, vessel movements could be increased into, out of, and inside of the Sydney Harbour. This is predominantly related to cruise vessels and commercial vessels. Sydney Harbour has been exclusively relied upon for this benefit description for data availability reasons.

More specifically, advice from a Demonstrator Project and sector experts suggests that there are four dominant circumstances in which vessel movements can be increased relating to improved accuracy and reliability of PPU predicts enabled by SBAS:

- Additional entries during low visibility such as in fog (five days)
- Air draft clearance beneath bridge (five days)
- Under keel clearance above seafloor (five days)
- Gains in area surveyed and time from survey to hydrographic charting (31 days).

This results in roughly 350 additional vessels per year able to manoeuvre into, out of and inside of Sydney Harbour. This calculation is based on almost eight vessels a day that berth in Sydney Harbour, derived from total pilotage vessels berthed divided by operative port days[240].

The economic impact of this theoretical increase in vessel capacity may manifest in various ways, including lower operating costs for vessel owners and lower shipping costs for shippers. However, as with UKC benefits, each commercial arrangement for a vessel is unique and so it is difficult to generalise this economic impact.

An increase in the potential vessel movements in a harbour environment may also have an impact on the revenue taken by a port authority. To this end, an average revenue per vessel calculation has been derived based on a pilotage vessel count divided by total port revenue derived from port operations[241]. This value has then been used as a proxy for total industry value lost.

A discount of 35 percent has then been applied to this figure to account for expectations around latent demand. Latent demand in this sense refers to the fact that just because there is capacity does not mean that it will be filled. It is acknowledged that at certain times of the year cruise berths in Sydney are at 100 percent utilisation. This coupled with official cruise documentation[242] further paints a forward picture of strong cruise (and hence vessel) demand that justifies a discount of 35 percent.

These anticipated benefits have then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table MA8.

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[240] Port Authority New South Wales (2018) Annual report. Accessed through: https://www.portauthoritynsw.com.au/media/3366/pa_064_ar_18_wcag_final-nov-2018.pdf

[241] Revenues from rental income and the navigation recharge (levy) has been ignored on the basis that it is irrelevant to SBAS and is an industry pass-through respectively.

[242] Cruise Lines International Association Australasia (2017) Australasian Cruise Industry capacity reports: market report Australia 2017. Retrieved from: https://www.cruising.org.au/Tenant/C0000003/Cruise%20Industry%20Source%20Market%20Report%20(1).pdf; NSW Department of Primary Industries (2018) Cruise development plan 2018. Retrieved from: https://www.industry.nsw.gov.au/__data/assets/pdf_file/0020/169013/NSW-Cruise-Development-Plan.pdf

Table MA8 – Benefits of increased vessel movements for Sydney Harbour only (30-year calculation)

Factor	Value	Notes
Total vessels entering Sydney Harbour under pilotage	77,370	30-year cumulative total
Total number of days where SBAS can increase vessel capacity in harbour for vessels under pilotage	1,375	Based on an annual rate of nearly 46 days per year where increased vessel capacity in harbour is possible
Total number of vessels under pilotage movements enabled through SBAS	10,600	Assuming eight vessels per day
Value of vessel movements enabled through SBAS	$216m	Revenue per vessel proxy derived from PANSW annual report
Value adjusted for latent capacity	$140m	A latent demand discount of 35% has been derived based on the outlook for the cruise sector
Gross value	$131m	Adjusted for uptake (linear, five-year uptake rate)
Present value	$53m	Discounted at 6.5%

Note: Totals may not sum due to rounding

12.6.5.3 Real-time hydrographic surveying

Over a 30-year assessment period, it is anticipated that PV$168m of economic benefits would accrue across all pilotage ports in Australia and New Zealand resulting from real-time hydrographic surveying.

Undertaking risk assessments, and regular hydrographic assessments, is critical in dynamic harbour environments. This need is greater in congested areas with large vessels manoeuvring, transit and small recreational craft. This activity is time and resource intensive and current methods necessitate a delay between acquisition of hydrographic data and charting.

SBAS has the potential to completely remove the need for post-processing which will generate significant value for harbour authorities across Australia and New Zealand.

To determine the average amount of time that will be saved, a Demonstrator Project advised that for any given year 93 days are taken up undertaking hydrographic surveys. This represents a mid-point between 85 days and 100 days which has been experienced for a given port in recent years.

Of these 93 days, it is assumed that six hours of processing time is undertaken per day. This is an average of the following rules of thumb in the industry:

- 0–1 hours of data collection results in four hours of post-processing time
- 4–6 hours of data collection results in six hours of post-processing time
- 8–10 hours of data collection results in eight hours of post-processing time.

This then results in an average of 555 hours of post-processing time per annum, or nearly 31 days[243].

To derive a value of this activity, assumptions have been made about both the hydrographic surveying team which is tasked with undertaking the post processing as well as pilots who are on standby waiting for instruction on the back of the outputs of the charting.

In short, it is assumed that:

- 25 percent of the hydrographic survey team's time would be freed up if post-processing activities related to positioning did not have to be undertaken.
- 50 percent of standby time for pilots would be freed up if post-processing activities did not have to be undertaken.

Estimated salaries for all individual occupations for a given port authority have then been used as a proxy for all pilotage harbours across Australia and New Zealand.

Finally, a total pilotage vessel count for Australia and New Zealand has been derived from a range of sources:

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[243] This assessment is based on an assumed 18 hours a day worth of operative port time for hydrographic surveying and post processing purposes.

- In the case of Australian vessel counts, Ports Australia data has been used[244]. This data has then been inflated to 2018 data using a combination of an extrapolation of cruise sector growth rates and alignment to GDP growth rates for commercial vessels.
- A report by Deloitte has been used to determine New Zealand vessels counts in 2018[245].

These counts have then been discounted to determine those vessels berthed under pilotage. The proportion of pilotage vessels in Sydney Harbour as a proportion of total vessels has been used as the proxy in this instance.

These anticipated benefits have then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table MA9.

Table MA9 – Benefits of real-time hydrographic surveying (30-year calculation)

Factor	Value	Notes
Total vessels count under pilotage	1.09m	30-year cumulative total for Australia and New Zealand
Value of time gained through increased production of latest nautical charts	$400	Based on proxies derived from Demonstrator Project – includes hydrographic survey team and pilots
Total value of time gained	$447m	
Gross value	$417m	Adjusted for uptake (linear, five-year uptake rate).
Present value	$168m	Discounted at 6.5%

Note: Totals may not sum due to rounding

12.6.5.4 Lower risk real-time navigation and pilotage

Over a 30-year assessment period, it is anticipated that PV$10m of economic benefits would accrue to PANSW resulting from lower risk real-time pilotage navigation in Sydney Harbour.

The fundamental premise of this benefit is that the SBAS signals will reduce the uncertainty in navigation and enable efficiency gains in vessel movements. This has the practical effect of increasing the capacity of the harbour to accommodate more vessels, more economically.

Determining the actual increase in harbour capacity (and hence vessel count) from the utilisation of the SBAS signals in real-time pilotage is challenging in lieu of conducting formal capacity modelling. However, by understanding upper and lower bounds of potential increases in vessel throughput, a mid-point assessment of two and a half percent throughput increase can be derived.

The lower-bound assessment is that the SBAS signals will have no discernible effect on vessel counts in a given harbour. Despite this, there is a notional reduction in navigation uncertainty allowing additional vessels to be accommodated.

An upper bound assessment can be derived in reference to real-time hydrographic survey benefits. Given that vessels still need a place to berth, even if they are technically able to enter a waterway, the upper bound of this benefit category is assumed to be five percent capacity improvement based on Sydney Harbour. This calculation is based on a function of the following, divided by total pilotage vessel counts in Sydney Harbour:

- Total additional days from real-time surveying (nearly 31)
- Vessel count per day (eight)
- Capacity factor (65 percent).

As with the economic benefits of reduced increased vessel capacity in harbour, this potential efficiency gain could manifest in various ways, including lower operating costs for vessel owners, lower shipping costs for shippers, and lower cruise passenger fares. However, each commercial arrangement for a vessel is unique and so it is difficult to generalise this economic impact.

Again, as with the economic benefits of increased vessel capacity in harbour, an increase in Sydney harbour capacity will have an impact on the revenue taken by PANSW, as the opportunity cost is less vessels berthing. To this end, an average revenue per vessel calculation has been derived based on a

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[244] Ports Australia (2015) Industry trade statistics. Retrieved from: http://portsaustralia.com.au/aus-ports-industry/trade-statistics/?id=60&period=15

[245] Deloitte (2017) Industry insight: New Zealand ports and freight yearbook. Retrieved from: https://www2.deloitte.com/content/dam/Deloitte/nz/Documents/finance/New-Zealand-ports-and-freight-report-2017.pdf

pilotage vessel count divided by total port revenue derived from port operations.

A discount factor of 35 percent has then been applied to this value to account for expectations around latent demand. This is generated on the same basis as the increased vessel capacity in harbour benefit.

This benefit has been limited to Sydney Harbour (and PANSW) in recognition of the unique features of all harbour environments and the difficulty of scaling estimates derived in a Sydney Harbour context.

These anticipated benefits have then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table MA10.

Table MA10 – Benefits of lower risk real-time pilotage for Sydney Harbour only (30-year calculation)

Factor	Value	Notes
Total vessels entering Sydney Harbour under pilotage	77,370	30-year cumulative total
Total additional vessels enabled through lower risk real-time pilotage	1,900	Based on a mid-point of harbour capacity (2.5 percent)
Total value of additional capacity	$39m	Revenue per vessel proxy derived from PANSW annual report
Value adjusted for latent capacity (65%)	$26m	A latent demand factor of 65% has been derived based on the outlook for the cruise sector
Gross value	$24m	Adjusted for uptake (linear, five-year uptake rate).
Present value	$10m	Discounted at 6.5%

Note: Totals may not sum due to rounding

It is worth noting, that if the same logic outlined above was applied to all other pilotage ports across Australia and New Zealand, then the benefits would be anticipated to be greater than $100m over a 30-year period.

12.6.6 Qualitative benefits – in harbour

12.6.6.1 Improved health and safety outcomes (pilots)

Reducing the need for pilots to physically board a given vessel (or at least reduce the physical imposition of large PPUs) can reduce health and safety risks (for example falls from ladders). A visual example of the dangers associated with this activity can be seen in Figure MA9.

Figure MA9 – Image of a pilot boarding a vessel[246]

Additionally, a Demonstrator Project advised that there is potential for cognitive-load improvements as pilots currently take most of their situational awareness from visual cues (which places a very high cognitive load on a given pilot). Transitioning these processes along the automation continuum[247] may provide cognitive benefits for pilots.

12.6.6.2 Safety benefits for harbour users

A Demonstrator Project has advised that as pilots are responding to information in real-time (or near real-time) it is anticipated that there would be the potential for fewer accidents (and near misses). This can lessen the likelihood for death and injury associated with maritime accidents (as well as reduced financial replacement costs and other disruption costs).

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[246] Credit: http://sailorsblog.com/wp-content/uploads/2017/09/Pilot-On-Ladder-2.jpg

[247] SBAS can facilitate movement along the automation continuum whereby pilots increasingly take situational awareness from both visual and digital (pilotage unit) cues to taking further reliance on the digital, to fully automated, instrument-driven awareness.

12.6.7 Quantitative benefits – at sea

12.6.7.1 Savings in the cost of subscription services

Over a 30-year assessment period, it is anticipated that a total of PV$9m of productivity benefits is possible through the deployment of the SBAS signals in replacing the costs of subscription services for various offshore activities.

The difference in cost between current costs of positioning subscriptions and the potential cost (or lack thereof) of access to the SBAS signals can result in savings for vessel operators in the cost of commercial positioning subscription services.

As noted in the anticipated benefits section of this Chapter, operators of DP vessels are expected to be the primary beneficiaries of the PPP signal as they need to subscribe to signal positioning services to ensure an appropriate level of positioning accuracy. There are assumed to be three types of DP vessels[248]:

DP Class 1

Vessels whose off-course drifting will not have any impact on the life of the crew or on any marine creature are generally enabled with a Level I DP system.

DP Class 2

A Level II DP system is built in a vessel whose off-course veering will tend to cause serious problems. A DP vessel enabled with a Level II DP system contains high-end computer applications and diving watercraft in case the vessel encounters any major problem in the deep sea. This represents the majority of DP vessels in Australasian waters[249].

DP Class 3

A Level III DP vessel contains similar equipment to a Level II DP system but with a backup DP system at some other location. A redundant system is used in a very high-risk operation, where the vessel must be able to maintain position subsequent to the loss of any single watertight compartment or any single fire sub-division.

These different types of DP vessels all have different subscription requirements. The number of receivers on these vessels can be used as a proxy for these requirements. A Demonstrator Project has identified that a DP Class 1 will likely have access to one subscription, a DP Class 2 has access to two subscriptions and a DP Class 3 has access to three subscriptions.

Due to the sensitivity around commercial contracts, the cost of signal subscription services varies and is difficult to quantify. Workshops completed through a Demonstrator Project estimated that a figure of USD$15,000 (AUD 22,500) per vessel per year is reasonable to use in this context.

There is no official report on the number of DP Class 1, 2 or 3 vessels operating from Australia and New Zealand and anecdotal information is inconsistent. Therefore, the industry publication 'Who's drilling' has been used as a basis for analysis which indicates that there were 58 working DP vessels in the Australian Offshore Drilling landscape[250].

Comparable information from 'Who's drilling' 4 March 2016 indicates that there were 118 vessels in operation. The lower end of this bound has been used and no growth in vessel counts has been assumed as the expectations for significant growth in vessel count is not expected in a carbon constrained environment[251].

Importantly, 'Who's drilling' does not provide a breakdown between DP vessels in Australian and New Zealand waters. Given the comparable larger proportion of offshore oil and gas activity in Australia vs New Zealand on a volume basis, scaling to New Zealand has not been undertaken.

These anticipated benefits have then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table MA11.

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[248] The following descriptions are all sourced from Kaushik, M. (2016) What is a dynamic positioning ship? Retrieved from https://www.marineinsight.com/types-of-ships/what-is-a-dynamic-positioning-ship/ Additional context has also been gathered from information provided by a Demonstrator Project.

[249] Information provided by a Demonstrator Project.

[250] Who's drilling, Pex Publications Pty Ltd, 13 April, 2018 Issue 1928.

[251] The fact that New Zealand specific information has not been provided adds an additional layer of conservatism.

Table MA11 – Savings in the cost of subscription services (30-year calculation)

Factor	Value	Notes
Total vessel count	1,740	58 DP vessels active in Australia and New Zealand waters in 2018 over 30 years (cumulative)
Total potential subscription cost per vessel	$22,500	Based on USD $15,000 per vessel assumption
Projected savings due to requirement for multiple subscriptions	$13,500	Vessel count information does not define DP classes - assumption that 60% of vessels will use SBAS.
Potential cost savings	$23.5m	Cumulative 30-year estimate
Gross value of savings	$21.9m	Adjusted for uptake (linear, five-year uptake rate).
Present value	$9m	Discounted at 6.5%

Note: Totals may not sum due to rounding

12.6.7.2 Savings in replacing Australian maritime DGPS network

Over a 30-year assessment period it is assumed that an asset replacement cost saving of PV$19m can be achieved through the deployment of SBAS in the marine sector.

AMSA's DGPS network has been running for almost 15 years and is nearing its end of life. AMSA has entered into a maintenance contract for the network over the next six years; however, once this period has elapsed, a decision will need to be made prior to this period elapsing to continue maintaining the current network with an increasing operating cost profile, replace the network, or decommission the network.

There is international precedent for the replacement of similar systems with SBAS[252]. SBAS would enhance the service currently performed by the DGPS as accuracy and coverage is expected to be enhanced under a SBAS investment. Crucially it would also offer an integrity message that can meet the 10 seconds to alarm standard set by the IMO.

The costs of operating the current DGPS network are currently met through the imposition of a levy on the industry. This implies that there is a public good that is generated through the presence of the network that warrants public intervention. In this sense, a decision to decommission the DGPS network without a replacement system would be a difficult proposition and would potentially raise the risk of higher frequencies of accidents (or near misses). Making a decision to decommission the network and rely on SBAS would mean the benefits of the network could continue to accrue and AMSA would then reduce levies or focus current levy monies on other valuable industry activities.

The presence of SBAS therefore both meets the positioning requirements of the current DGPS network and would represent a viable alternative at low (or even no) cost to AMSA and the industry. Hence there would be benefits that accrue owing to avoided capital (and operating cost) investment over the period of the analysis.

Specific costs estimates have been provided as part of this assessment, but in the interests of confidentiality, a high-level breakdown of the estimated capital and operating costs of the DGPS network is provided below:

- Capital costs include: new masts, new transmitter, new antenna tuning units, and new reference station integrity monitors.
- Operating costs include: maintenance contract(s), lease costs, personnel costs associated with asset replacement, utilities costs (power and telecommunications), and contingency costs.

The anticipated capital replacement costs are estimated by AMSA to be roughly $6m each asset replacement cycle. This cycle is assumed to be every 15 years and so it is likely that there would be two major replacements over the 30-year period of this analysis.

Operating costs savings of between $780,000 and $860,000 per annum are also envisaged.

In practice it is assumed that there would also be some minor decommissioning costs associated with a retirement of this network. These have been considered of insufficient size to accommodate in this analysis.

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[252] European Global Navigation Satellite System Agency (2018) GNSS user technology report: issue 2. Retrieved from: https://www.gsa.europa.eu/system/files/reports/gnss_user_tech_report_2018.pdf

12.7 Summary

Table MA12 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning. The quantifiable economic impact of L1, DFMC and PPP in the maritime sector is anticipated to be **PV$588m** over 30 years.

This economic value is highly conservative given the focus of many of these benefit categories on a single port, when the benefits would extend across a much wider range of ports throughput Australia and New Zealand.

Table MA12 – Benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
On port				
Reduction in misplaced containers	Sub-metre (horizontal and vertical)	DGNSS currently used but prone to blackouts	16,000 misplaced containers over a 30-year period. This is anticipated to generate $28m in operating savings.	L1, DFMC, PPP
Enhanced port planning	Sub-metre (horizontal)	DGNSS currently used but prone to blackouts	Efficiency associated with port planning during blackouts amounts to $205m.	L1, DFMC, PPP
Reduction in health and safety risks on port	Sub-metre	DGNSS currently used but prone to blackouts	Continued operation of automated and semi-automated ports through blackout events reduces human exposure to health and safety risks.	L1, DFMC, PPP
In harbour				
Under keel clearance management	10–15cm (vertical)	Various, with RTK systems often being employed.	A total of $97m of productivity benefits is possible for a single Australian port from enhanced UKC management system.	PPP
Increased vessel capacity in harbour	Horizontal and vertical	Most ports use PPUs as an aid to pilotage but all are limited to GNSS aiding only.	It is anticipated that an increase in 10,600 vessel movements is possible in Sydney Harbour resulting in $53m of economic benefits.	L1, DFMC, PPP
Real-time hydrographic surveying	Various (horizontal and vertical)	Many ports currently employ CORS to achieve required accuracy.	It is anticipated that $400 per vessel in avoided costs can be obtained by reducing the time taken to undertake post processing of hydrographic data, resulting in a total saving of $168m.	PPP
Lower risk real-time navigation and pilotage	Various (horizontal and vertical)	Most ports use PPUs as an aid to pilotage but all are limited to GNSS aiding only.	Anticipated that an increase in 1,900 vessel movements in Sydney Harbour could result in benefits of $10m.	L1, DFMC, PPP
Improved health and safety outcomes (pilots)	Various	Most ports use PPUs as an aid to pilotage but all are limited to GNSS aiding only	Reducing the need for pilots to physically board a given vessel can reduce health and safety risks (for example falls from ladders).	L1, DFMC, PPP
Safety benefits for harbour users	Various	Some ports currently deploy PPUs that use GNSS aiding	As pilots are responding to information in real-time (or near real-time) it is anticipated that there would be the potential for fewer accidents (and near misses).	L1, DFMC, PPP

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
At sea				
Savings in the cost of subscription services	10-15cm (horizontal and vertical)	Various correction subscription services which come at a cost	$9m through the removal of the cost of the subscription services.	PPP
Savings in replacing Australian maritime DGPS network	Sub-metre (horizontal)	DGPS infrastructure considered base case	Replacement of DGPS system with SBAS can result in $19m in avoided operating costs and capital costs.	L1, DFMC

A range of additional applications in the maritime sector have been identified throughout this research but have not been quantified (or described qualitatively) for a range of reasons[253]. A collection of these applications is provided in the additional applications Chapter 18.

12.8 Assumptions and limitations

The economic modelling undertaken for this sector has been based on a combination of official data sources, desktop research, information provided by the Demonstrator Project as well as rational and logical assumptions. These assumptions have all been agreed in discussion with the relevant Demonstrator Project and FrontierSI.

In addition to standard caveats around economic modelling, the following assumptions and limitations are worth highlighting:

Scaling

It is important to note that many of the maritime benefits have not been scaled across the sector or across jurisdictions given the unique arrangements of harbour environments. This is most relevant for the UKC benefits, increased harbour capacity benefits and lower risk real-time pilotage where the quantitative benefits accrue to a small sub-set of harbour environments – all located in Australia.

This means that the estimates included in this Chapter are likely to be considerable underestimates of potential economic benefits.

Present value discount

All quantitative benefits have been discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

(Semi) Automated ports

For all on-port benefits, it is assumed that these will accrue to automated, and semi-automated ports. This assessment is based on the current levels of automation at automated and semi-automated ports across Australia and New Zealand. It is possible that other ports may increase levels of automation in time – but this will also come with a high up-front capital cost that has not been considered in this analysis.

Benefit heterogeneity

It is probable that the benefits of an operational SBAS will be experienced by a wide range of beneficiaries (vessel owners, port operators, shippers of freight etc) simultaneously. However, only one value metric related to the above beneficiaries has been used for modelling purposes.

Latent demand

A latent demand factor for Sydney Harbour has been assumed based on a qualitative understanding of existing capacity constraints and available berth space. It is understood that at increasing times of the year, Circular Quay is near capacity utilisation which indicates that there is significant latent demand. Additionally, regional documentation points to increased cruise volumes and increased GDP growth which will impact on commercial vessel growth.

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[253] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

Rail sector

Key findings

Rail plays a varied role across Australia and New Zealand but generally comprises bulk freight, non-bulk, break-bulk and passenger transport movements. Improvements through the use of the SBAS signals can generate benefits to the sector in many ways – from better asset management to operational productivity improvements.

Highlights

The quantifiable economic impact of the SBAS signals – L1, DFMC and PPP – in the rail sector is anticipated to be **PV AUD$193m** over 30 years. These benefits solely accrue to operating expenditure savings and are anticipated to result in:

- 11m maintenance crew labour hours unlocked to focus on new and improved maintenance tasks due to enhanced geo-referencing of network defects. This generates savings of **PV$136m** in productivity benefits to the sector over 30 years.
- 5m rail planner labour hours unlocked for new and improved back-office tasks due to efficiencies in planning maintenance works. This has a value of **PV$57m** to the sector over 30 years.
- Reduction in network downtime due to maintenance task efficiency improvements, thereby improving the productivity of the rail sector, and its contribution to the wider economy.
- Enabled GNSS-based signal systems and moving block settings, which is anticipated to reduce headways, improve frequencies and free up wider network capacity. This can generate cost savings through divestment of existing terrestrial-based signal infrastructure.

Quantifiable benefits

Figure RA1 – Benefits by geography (30-year, AUD)

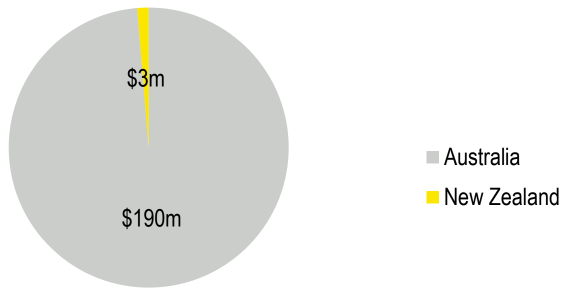
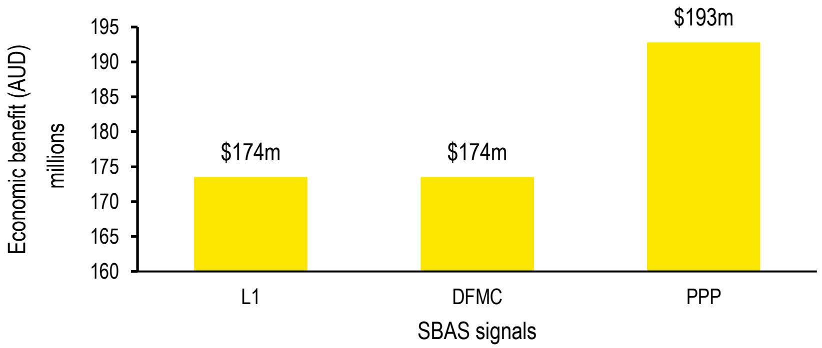


Figure RA2 – Benefit by signal type (30-year, AUD)



13. Rail sector

13.1 Sector description

The rail industry has traditionally played a significant role in both the Australian and New Zealand economies through the facilitation of freight from inland industry to ports. For example, in Australia approximately 49 percent of Australia's national freight task (1.2b net tonnes) was carried by rail in 2014–15[254], and as of 2017 its value to the Australian economy has been estimated at $26b a year[255]. Rail freight in New Zealand makes up a smaller, yet material 16 percent of the total freight task and is estimated to contribute approximately $1.5b to the economy per annum[256].

Rail across both countries also plays a significant role in the movement of people for commuting and recreational reasons (passenger transport), both in the form of heavy rail (larger, longer, and heavier forms of rail such as subways) and light rail (lighter and slower rail at street level and within the road corridor).

13.2 Use of positioning technology

The rail sector is characterised by investments in long-lived assets and infrastructure. Many locomotives are 20 to 30 years old, wagons are typically used for 30 to 40 years, and signalling systems are maintained for 20 to 50 years. Investments in new track can be expected to last for at least 50 years if adequately maintained, which has implications for the possible delay in uptake of new technologies[257].

Nevertheless, the rail sector has a history of utilising both standalone and augmented GNSS for various maintenance and operational tasks. Standalone GNSS is currently used as a valuable tool by track managers and train operators for asset management, improved efficiency of asset use, and to provide improved customer service, i.e. through monitoring of trains against schedules.

At present, the main use of augmented GNSS in the rail sector is surveying of train tracks using specialised surveying trolleys which require support from terrestrial base stations or other commercial augmentation solutions. Modern train management requires accurate maps of the railway including centre line, curvature, gradient, and signalling infrastructure positions. Historical maps of asset locations are not sufficiently accurate for some modern applications and so an exercise of remapping for accurate positioning is required[258].

A lack of precision and reliability in GNSS positioning in the past, where augmented GNSS has not been available, has led to the development of alternative or parallel technologies to establish train positioning. This has traditionally led to inefficient back-office operations, specifically rail planning tasks involving the coordination of train scheduling and maintenance tasks, to maintain acceptable safety standards[258].

13.3 Demonstrator project descriptions

One Demonstrator Project was commissioned to investigate the potential benefits of the SBAS signals to the rail sector. The Position Partners/TasRail Demonstrator Project trialled the SBAS signals throughout the TasRail network (which is somewhat representative of state, or provincial, network operators throughout Australia and New Zealand). Additional discussions were conducted with Australian and New Zealand rail operators to ascertain the applicability of the Position Partners/TasRail benefits to the wider rail sector.

Further details around the Position Partners/TasRail Demonstrator Project are contained in Table RA1.

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[254] Department of Infrastructure and Regional Development, *Submission 14,* to the Senate Standing Committee on Rural and Regional Affairs and Transport (2017) An inquiry into Australia's rail industry. Retrieved from: https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Rural_and_Regional_Affairs_and_Transport/Railindustry45/Report

[255] Deloitte Access Economics (2017) Value of rail: the contribution of rail in Australia. Retrieved from: https://www2.deloitte.com/content/dam/Deloitte/au/Documents/Economics/deloitte-au-economics-value-rail-contribution-australia-161117.pdf

[256] EY (2016) The value of rail in New Zealand. Retrieved from: https://www.kiwirail.co.nz/uploads/Publications/The%20Value%20of%20the%20Rail%20in%20New%20Zealand.pdf

[257] Acil Allen (2013) Precise positioning services in the rail sector: an estimate of the economic and social benefits of augmented positioning services in the rail sector. Pp 1. Retrieved from: http://www.ignss.org/LinkClick.aspx?fileticket=rpl6Blao%2F54%3D&tabid=56

Table RA1 – Rail sector Demonstrator Project description

Demonstrator Project	Description	Signals tested
Position Partners/TasRail	Investigating the benefits of the SBAS signals for minimising ghosting and false alarms generated by GNSS positioning on trains and aid in more accurately locating maintenance defects. It is anticipated the SBAS signals could be used for train control and management systems, and predictive maintenance.	L1, DFMC, PPP

13.4 Anticipated benefits

In attempting to understand the material economic benefits for the sector, and the potential economy-wide implications from the implementation of the SBAS signals, a benefits mapping exercise was undertaken with the sector. This led to the identification of four anticipated benefits.

Reduction in labour hours per maintenance task

The identification and ongoing monitoring of network defects within the sector is still largely undertaken through manual processes. Inspectors will physically mark a fault using paint, whilst recording its position relative to network reference points (often one kilometre apart) and whether it is on a northbound or southbound track. This information is passed onto maintenance crews who then use it to relocate a fault and carry out the maintenance task.

A significant amount of labour hours are exerted attempting to relocate defects using paint and reference points, which is further compounded if paint markings have faded or reference points have been damaged. The SBAS signals are anticipated to enable the accurate geo-referencing of network defects, thereby reducing the number of labour hours spent on maintenance tasks as crews can be directed to the location via the most effective path and locate defects more quickly.

More efficient back-office functions

The manual and imprecise nature of identifying, relocating, and repairing network defects means additional back-office processes are required to mitigate potential risks. For example, accurate geo-referencing of network defects would require rail planners to spend less time cross referencing and double checking such tags to ensure they are accurate prior to deploying maintenance crews.

It is therefore anticipated that quicker identification of maintenance tasks through more accurate geo-referencing would remove the need for inefficient back-office functions (primarily related to rail planning tasks and resource utilisation) enabling greater efficiencies to be realised or higher-value activities to be pursued.

Reduction in network downtime

For every maintenance task, operators are required to either shut down the track, or impose temporary speed restrictions (TSRs) around unresolved defects, or live work sites for the health and safety of contractors. Both come at the expense of system productivity.

In addition to labour hour savings, quicker maintenance tasks enabled by the SBAS signals are anticipated to reduce the amount of downtime experienced by a network per annum. This presents potential for significant upside in the form of greater freight and/or passenger volumes moved on the network, resulting in direct revenue benefits for operators, and productivity benefits for the wider economy.

Reduced headways via enablement of GNSS-based signal systems

A headway is typically defined as the time between consecutive rail services. If you catch a train that comes every half hour, then the service you catch has a headway of 30 minutes. The SBAS signals are anticipated to enable operators to move from a fixed block setting to a moving block setting. This means moving from a system where train positions are only known at the transponder locations and therefore require a constant worst-case headway based on discontinuous location monitoring, to a system that provides continuous, precise, and timely train position information. This transition will enable reduced headways.

In addition, the move to a moving block setting is anticipated to reduce reliance on costly terrestrial signal infrastructure, and associated on-board equipment, which may support long-term cost savings for operators.

The anticipated rail benefits have been classed under benefit categories as per Table RA2.

Table RA2 – Rail sector benefit categorisation

Benefit	Benefit category	Quantitative?
Reduction in labour hours per maintenance task	Operating expenditure savings	Yes
More efficient back-office functions	Operating expenditure savings	Yes
Reduction in network downtime	Operating expenditure savings	No
Reduced headways via enablement of GNSS-based signal system	Operating expenditure savings	No

13.5 Positioning needs and current methods

The focus of the positioning needs and current methods section is on the positioning requirement for geo-referencing network defects, and current tools and processes used to undertake the task. Accurate geo-referencing of defects is anticipated to drive maintenance and back-office efficiencies within the sector.

13.5.1 Reduction in labour hours per maintenance task

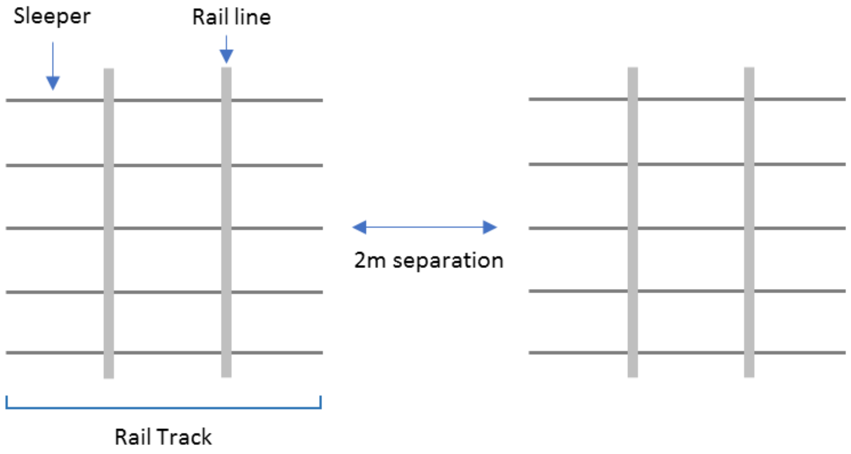
In simple terms, this benefit anticipates the SBAS signals to reduce time spent locating network defects, which will translate into less time spent per maintenance task. There are two key positioning factors required for the accurate and effective geo-referencing of network defects. The first factor is considered more important and involves accurately identifying which track a defect lies on, i.e. whether it is on the northbound track(s) or southbound track(s)[258]. Understanding which track a defect is on minimises the risk of sending maintenance crews down the wrong track.

As shown in Figure RA3, the two-metre separation between sleepers on parallel tracks[259] suggests that as a minimum, sub-metre positioning is required to differentiate between tracks. Standalone GNSS is unsuitable for this process given its margin of error, which may incorrectly geo-tag defects on the wrong track.

The second factor is the ability to accurately identify the location of specific faults on a given track. The positioning requirement for this data point is variable, as the more accurate the positioning information is, the less time a maintenance crew is likely to spend searching for a fault. Whether the margin of error is ±10 metres under standalone GNSS, or a sub-metre under L1 and DFMC, is unlikely to make a material difference to labour time savings.

Given the inaccuracy of standalone GNSS, the identification of network defects currently involves two distinct steps. The first is the physical marking of a defect, which is generally carried out using paint and in some instances a photograph, and the second is the geo-referencing of the defect using physical reference markers.

Figure RA3 – Depiction of rail sleeper separation



To geo-reference a defect, inspectors utilise reference markers which are placed evenly apart throughout the network. Generally, all reference markers are identified by their distance relative to a common location. Inspectors then geo-reference a defect relative to a specific reference marker.

There are two limitations associated with the current approach. First, the deployment of paint or other physical markers leaves open the risk of fading or removal due to many causes, such as weather or vandalism. This can mean that maintenance crews spend longer than is necessary trying to locate a

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[258] Note that in the event of three tracks or more, the need for high-resolution positioning becomes even more critical due to the greater network complexity

[259] A rail sleeper is the rectangular support structure in railroad tracks, which is laid perpendicular to the rail line(s) to provide support and stability. Various points of clarification have been sought with participants in a Demonstrator Project to confirm that two metres is sufficient separation.

faded paint marker, or even worse, having to return to base without repairing the defect because the marker has been removed or cannot be found. This can prove especially costly because an inspector is then required to return to the scene to re-mark a defect and the maintenance crew must also then be redeployed to the site to carry out repair works.

Second, the use of reference markers has two specific risks which compound the inherent inaccuracies of attempting to gauge one's position relative to such a marker. The first risk is that markers can be incorrectly read or recorded by people who are not familiar with the system. This is a material risk where contractors, who are unfamiliar with the network, perform maintenance tasks. The second risk is that similarly to paint markings, reference markers can be rendered obsolete due to adverse weather events or vandalism. An example of this may be the destruction of markers due to heavy rain during storm events.

The SBAS signals are anticipated to enable accurate and efficient geo-referencing of network defects, thereby eliminating the need for existing manual processes, which are prone to degradation and misreading. This is anticipated to generate labour time savings for maintenance staff as well as related back-office functions.

13.5.2 More efficient back-office functions

Improved back-office productivity is directly linked to more efficient maintenance tasks. Therefore, the positioning needs and current methods for capturing this benefit are the same as metrics used for reduced labour hours spent per maintenance task, in that both depend on accurate geo-referencing of network defects.

13.5.3 Reduction in network downtime

As with the back-office efficiency benefit, reduced network downtime is also directly linked to more efficient maintenance tasks. Therefore, the positioning needs and current methods for capturing this benefit are the same as metrics used for reduced labour hours spent per maintenance task, in that both depend on accurate geo-referencing of network defects.

13.5.4 Reduced headways via enablement of GNSS-based signal system

The fundamental positioning requirement of GNSS-based signal systems is the accurate tracing of trains relative to one another. As with the detection of defects, the positioning requirement consists of both absolute positioning along a track, as well as being able to distinguish between tracks. The length and practical headways between trains mean the SBAS signals stand to provide minimal benefit with regards to absolute positioning along a track. However sub-metre positioning enabled by the SBAS signals would be critical for locating a train to the correct track, given the two-metre separation between railroad ties. Furthermore, given the importance of positioning information in a GNSS-based signal system, SoL integrity (as provided by L1 and DFMC) would also be a pre-requisite.

13.6 Sector benefits

13.6.1 Signal attribution

The typical two-metre horizontal separation between tracks means that sub-metre level accuracy is likely to be sufficient to accurately geo-tag a defect to the correct rail track. Hence, Table RA3 demonstrates that L1 and DFMC are anticipated to enable 90 percent of these economic benefits, with PPP accruing 100 percent of benefits due to incremental decimetre accuracy afforded by this technology.

The benefits accrued by PPP remain limited to geo-referencing of defects. In the absence of SoL integrity PPP is unsuitable for GNSS-based signal systems.

It is also worth noting that quantifiable benefits reflect the augmentation of existing manual/semi-automated processes within the sector. It is acknowledged that the SBAS signals will still be subject to areas of significant obstruction (including virtual and real tunnels) in the rail environment and additional sensors will be required as part of a rail positioning system.

Indicative test results provided by FrontierSI are representative of the testing carried out by the SBAS Demonstrator Project in this sector. Where deviations exist, DFMC SBAS results are expected to be similar to SBAS L1 in an operational system.

The testing was carried out with professional equipment in a range of settings, including partial to significantly obstructed environments. Values are presented at a 95 percent confidence interval.

Table RA3 – Rail sector signal attribution

Signal	Rail sector test results	
	Expected horizontal performance(m)	Expected vertical performance (m)
L1	0.6	0.6
DFMC	1.3	3.4
PPP	0.3	0.6

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Quantitative benefits					
Reduction in labour hours per maintenance task	Sub-metre	90%	90%	100%	Sub- metre accuracy required to differentiate parallel tracks
More efficient back-office functions	Sub-metre	90%	90%	100%	Sub- metre accuracy required to differentiate parallel tracks
Qualitative benefits					
Reduction in network downtime	Sub-metre	✓	✓	✓	Benefits tied to enhanced geo-referencing position requirements
Reduced headways via enablement of GNSS-based signal system	Sub-metre	✓	✓	-	Sub-metre position accuracy sufficient for moving block setting to enable differentiation of parallel tracks. Integrity message also likely to be required.

13.6.2 Uptake rate

Discussion with the sector suggests the rail sector is generally cautious when adopting new technologies. Once there is confidence in the technology, uptake is generally quite fast before tapering off as smaller operators come online towards the end of the assessment period. Uptake within the sector may also be affected by renewal cycles, which typically conform to a 50-year investment cycle. Based on this uptake assessment, an S-curve uptake has been deployed for all benefits in the rail sector.

13.6.3 Quantitative benefits

13.6.3.1 Reduction in labour hours per maintenance task

It is anticipated that almost 11m labour hours will be freed up over a 30-year assessment period for maintenance tasks due to the enhanced geo-referencing of network defects afforded by L1 and DFMC. This is anticipated to generate PV$136m in operational productivity benefits for the rail sector.

The primary data inputs for this calculation have been derived from estimates from the Demonstrator Project and then scaled up to a sector-wide benefit across Australia and New Zealand.

Discussion with the sector suggests enhanced geo-referencing of defects could generate at least a 0.5 labour hour saving per rail maintenance worker, per week, based on conservative estimates. A key challenge in the quantification of this benefit has been to understand the maintenance crew headcount across Australia and New Zealand to which these labour savings apply. After discussions with the sector, wear and tear on the network has been used as a proxy for establishing the scale of the maintenance workforce. Based on further discussions with the sector, wear and tear on a network and the corresponding maintenance workforce requirements are driven largely by the weight borne. This is described as gross tonne kilometres (GTK), which represents all above-track rail weight (including locomotives, wagons, freight, payloads, and passengers) carried over the length of one kilometre[260].

To ascertain total GTK, a mix of statistical data, proxies and assumptions sourced from the sector have been used to understand the weight of freight tasks, passenger boarding, and locomotives.

This has amounted to an Australia GTK figure of 722b GTK, nearly 70 times greater than New Zealand's 2016 GTK of 10b. This difference in scale is explained by Australia's larger freight task moved by rail (49 percent in Australia compared to 16 percent in New Zealand) and greater population

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[260] Indian Railways (2006) Annual report and accounts 2006–07. Retrieved from: http://www.indianrailways.gov.in/railwayboard/uploads/directorate/stat_econ/annual-rep-0607/glossary.pdf

densities which enable more passengers to board simultaneously. The greater size of the Australian network means it experiences greater quantum of wear and tear, which requires proportionally more maintenance activity and a greater number of maintenance staff.

in lieu of sufficient publicly available data, the GTK proxy was utilised to establish the total maintenance headcount for the entire rail sector across Australia and New Zealand. The number of GTKs per maintenance worker was determined using Demonstrator Project data about maintenance worker arrangements. This calculation was then applied to the total sector-wide GTK to estimate a rail workforce size for Australia and New Zealand in 2020.

The anticipated benefit resulting from reduced labour hours to complete maintenance tasks was adjusted for uptake and discounted to present values to arrive at the economic saving shown in Table RA4.

Table RA4 – Reduction in labour hours per maintenance task calculation breakdown (30-year calculation)

Factor	Value	Notes
Total maintenance headcount	827,000	Calculated using 32m GTK per worker proxy. Note: result is a sum of maintenance workers over 30 years
Estimated labour hour saving	21m hours	Headcount multiplied by 30min saving per week over 50 weeks
Adjusted for uptake	11m hours	S-curve over 30 years
Value of labour hours saved	$505m	Multiplied by per hour labour cost of $46
Present value	$136m	Discounted at 6.5%

Note: Totals may not sum due to rounding

13.6.3.2 More efficient back-office functions

Enhanced geo-referencing of network defects is anticipated to simplify maintenance tasks, as well as improve associated back-office functions related to workforce, maintenance, and rail operation planning. This is anticipated to result in a total labour time saving of 5m hours over a 30-year period resulting in PV$57m in benefits.

A key finding from consultations with the sector is that labour time savings will likely result in a freeing up of resources to undertake higher value work elsewhere in organisations. The enhanced overall operational productivity is anticipated to generate a one-hour time saving per rail planner per week on average.

The anticipated benefit resulting from more efficient back office functions was adjusted for uptake and discounted to present values to arrive at the economic savings shown in Table RA5.

Table RA5 – Back-office cost savings calculation breakdown (30-year calculation)

Factor	Value	Notes
Total rail planner headcount	172,000	Calculated using 154m GTK per worker proxy. Note: result is a sum of back-office workers over 30 years
Estimated labour hour saving	9m hours	Headcount multiplied by 1 hour saving per week over 50 weeks
Adjusted for uptake	5m hours	S-curve over 30 years
Value of labour hours saved	$210m	Multiplied by per hour labour cost of $46
Present value	$57m	Discounted at 6.5%

Note: Totals may not sum due to rounding

13.6.4 Qualitative benefits

13.6.4.1 Reduction in network downtime

In addition to direct costs associated with repairing defects on the rail network, a wider economic productivity cost benefit can be anticipated.

Trains are required to reduce their travel speeds through work sites or areas with unresolved defects when maintenance is being performed. Alternatively, rail lines are closed off to trains completely. These operational decisions promote worker and passenger safety as well as ensuring asset protection.

Discussion with the sector suggests that efficient maintenance tasks have the potential to reduce network downtime, thereby improving network capacity. This is likely to result in an increase in revenue from increased passenger throughput and freight shipped. The scale of these benefits is unknown but expected to be materially significant.

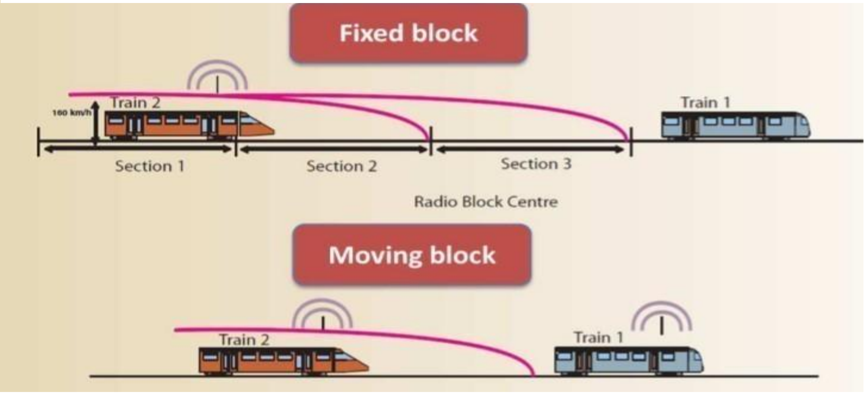
The large degree of variability in networks within the rail sector and commercial sensitivities in ascertaining key data inputs, make accurately understanding the uptake of this capacity a difficult task. Numerous factors such as user demand, operator capability, train capacity, and regulatory compliance also raise analytical complexity, which is why analysis of this benefit has remained at a qualitative level.

13.6.4.2 Reduced headways via enablement of GNSS-based signal systems

Railway signalling serves as the primary baseline safety system to control the movement of trains within the rail sector. In general, these signalling systems are automatic by means of electronic track circuits and transponder, which provide the exact position of the train as it passes by[261]. The motivation behind this safety system is the need for much greater stopping distance for trains than the stopping distance for cars on roads. The need for greater stopping distances can be attributed to the tenuous contact between steel wheel and steel rail.

Currently most signal systems operate in a fixed block setting. As depicted in Figure RA4[262], such systems signals are placed at the beginning and end of each block, which is a section of track between two fixed points. Each is preceded by transponders which detect the train's position as it passes by. Train positions are only known at the transponder locations, and therefore display a constant worst-case headway based on discontinuous location monitoring.

Figure RA4 - Fixed block vs moving block setting



A moving block setting on the other hand, does not make use of fixed points, but rather is based on continuous, precise, and timely information on the location of the front and rear of the train. This in turn enables operators to reduce headways and increase line capacity. GNSS is considered an enabling technology of such a setting and can be used with other types of sensors to maximise continuity and integrity[262].

For moving block settings to work operators need to know the exact location of the front and rear of a train. At the very least, current research topics on this topic infer sub-metre accuracy is required to enable a GNSS-based signal system.

The immaturity of GNSS-based signal systems enabling moving block settings means that there is currently no consensus on the ideal supporting positioning technology. For example, inherent inaccuracies prevalent in standalone GNSS means it remains unsuitable as a positioning solution. While other augmentation methods can offer the necessary positioning accuracy, systems such as RTK require costly base stations along a network and require mobile coverage to transmit correction signals which can prove problematic in isolated areas.

Research[262] suggests that L1 and DFMC may be a strong alternative given the enhanced positioning accuracy afforded, improved continuity, and integrity of

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[261] Kassabian, N., Lo Presto, L. and Rispoli, F. (2014) Augmented GNSS differential corrections minimum mean square error estimation sensitivity to spatial correlation modelling errors. Sensors 2014, 14, Pp 10258-10272. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4118345/pdf/sensors-14-10258.pdf

positioning information, along with reduced requirement for supporting terrestrial infrastructure.

Once implemented, a moving block setting has the potential to generate two distinct benefits to operators. First, the reduction of headways frees up capacity on existing networks, enabling improved frequencies and potentially enhancing economic productivity by deferring planned capital expenditure and enabling faster movement of goods.

The second benefit accrues to operators directly, in that a GNSS-based moving block setting removes the need for:

- Installation and maintenance costs of trackside signals
- Train signalling on-board equipment costs
- Costs related to standardised communication between the trackside and on-board equipment[262].

This has the potential to generate significant capital and operating expenditure savings for the rail sector in the long-term.

13.7 Summary

Table RA6 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning. The quantifiable economic impact of L1, DFMC, and PPP in the rail sector is anticipated to be **PV AUD$193m** over 30 years.

Table RA6 – Summary of benefits (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Reduction in labour hours per maintenance task	Sub-metre	Manual processes currently utilised for defect positioning	11m labour hour savings at a value of $136m	L1, DFMC, PPP
More efficient back-office functions	Sub-metre	Manual processes currently utilised for defect positioning	5m labour hour savings at a value of $57m	L1, DFMC, PPP
Reduction in network downtime	Sub-metre	Manual processes currently utilised for defect positioning	Improved productivity for wider economy and revenue for operators	L1, DFMC
Reduced headways via enablement of GNSS-based signal system	Sub-metre	No base case identified to date given the immaturity of technology	Improved network efficiency	L1, DFMC

A range of additional applications in the rail sector have been identified throughout this research but have not been quantified (or described qualitatively) for a range of reasons[263]. A collection of these applications is provided in the additional applications Chapter 18.

13.8 Assumptions and limitations

The economic modelling undertaken for this Chapter is based on a combination of official data sources, desktop research, information provided by the Demonstrator Project, as well as the use of rational and logical assumptions. These assumptions have all been agreed in discussion with the relevant Demonstrator Projects and FrontierSI.

In addition to standard caveats around economic modelling, the following assumptions and limitations are highlighted:

Present value discount

All quantitative benefits are discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

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[262] Ministry of Transport (2014) National freight demand study. Retrieved from: https://www.transport.govt.nz/assets/Uploads/Research/Documents/National-Freight-Demand-Study-2014-executive-summary.pdf

[263] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

GTK growth rate

The GTK growth rate has been assumed to be one percent year on year over the 30-year forecast period.

Scalability

GTK is assumed to be a sufficiently accurate proxy for scaling purposes, both within the Australian rail sector and in the New Zealand rail sector. To complete scaling across jurisdictions, an assessment of the total GTK per maintenance crew member and rail planner for the Demonstrator Project has been estimated. This has then been used to divide total GTK across Australia and New Zealand to ascertain total estimated headcount figures. Furthermore, it has been assumed that the maintenance crew and rail planner per GTK proxy is largely reflective of the average rail network (heavy rail and light rail) across Australia and New Zealand.

Passenger GTK calculation

Passenger GTK is the summation of net tonne kilometres (NTK), which counts passenger weight transferred per km of rail line, and tare tare kilometres (TTK) which reflects the weight of the underlying locomotive. Freight NTK data has been sourced from statistical sources, whilst passenger NTK data has been derived using the following equation provided by sector experts:

NTK = passenger boarding's x travel distance x per passenger weight

For the purposes of this analysis, an average travel distance of 13.5km and an average weight allowance of 65kg per passenger has been assumed and checked with rail sector participants. Passenger boardings for both heavy and light rail have been derived from statistical sources. In addition, TTK figures are based on 132T EMU3 and 264T EMU6 locomotives.

Maintenance crew and back-office labour costs

Labour costs for both maintenance crew workers and back-office workers are assumed to be the same at $46 per hour (excl. overheads).

Resources sector

Key findings

The resources sector comprises the exploration, mining and production of minerals, oil, and natural gas which continue to play a strong role in the Australian and New Zealand economies.

Highlights

Total benefits of PV AUD$1.58b are anticipated in the resources sector from the deployment of the SBAS signals – L1, DFMC and PPP – over a 30-year period. A selection of benefits consists of:

- PV$636m in operating expenditure savings associated with better material management, resulting in additional 64m tonnes of iron ore able to be produced over a 30-year period.
- PV$577m in operating expenditure savings over a 30-year period associated with efficient haul truck fleet speeds enabled by improved collision avoidance system (CAS) effectiveness.
- 23m tonnes more iron ore production enabled through better shovel productivity, which can result in PV$229m in operating expenditure savings over a 30-year period.
- 205,000 hours of haul truck vehicle downtime avoided resulting in an operating saving of PV$130m over a 30-year period.

It is noted that the benefits applicable to New Zealand may be smaller than expected due to the nature of the mining operation of one of the Demonstrator Projects. I.e. because New Zealand doesn't have an iron ore market, many of these benefits do not accrue in a New Zealand context.

Quantifiable benefits

Figure RES1 - Benefits by benefit category (30-year, AUD)

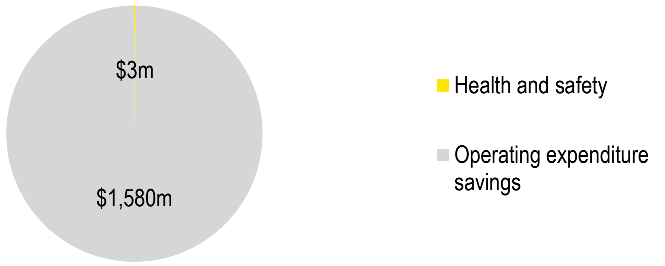
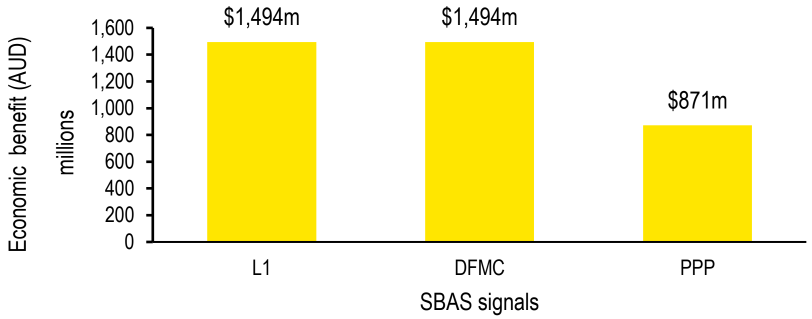


Figure RES2 - Benefits by geography (30-year, AUD)

Figure RES3 - Benefits by signal type (30-year, AUD)



14. Resources sector

14.1 Sector description

The resources sector comprises the exploration, mining, and production of minerals, oil, and natural gas, which have traditionally played a strong role in the Australian economy[264] and a smaller but still material role in the New Zealand economy.

The resources sector supports the growth of the economy through contribution to exports, employment, government revenue, and direct investment. Other benefits include contributions to rural and regional development, technology innovation, and environmental research[1].

While the size and operational configuration of different mining operations differs by mineral/mine type and location, it is assumed that the main benefits of the SBAS signals will incrementally accrue to the larger mining operations that have made significant investments in capital equipment.

14.2 Use of positioning technology

The way positioning technology is used in the resources sector differs from mine to mine and differs across the types of activities that are being undertaken. The general trend across the sector, however, is for increased use of positioning systems, as a higher level of capital investment and automation on-site can result in profound productivity improvements[265].

Positioning needs are varied but for the purposes of this Chapter predominantly relate to:

The tracking of capital equipment (including vehicles)

Typically, larger mine sites will employ high-precision GNSS systems on critical capital equipment such as loaders, but may have a lesser (or no) positioning system associated with smaller and less critical pieces of equipment.

The need to understand the current or future location of mining boundaries

The need to establish mine sites, as well as prospecting and exploration activity, is a critical part of mining operations. This extends from drilling activity, through to the location of mineral deposit, and the protection of environmentally and culturally sensitive areas. In many instances the use of specialist surveying teams is commonplace.

The specific level of positioning performance required for a particular application is often determined on a case-by-case basis and there are currently no regulated standards with respect to positioning requirements on mine sites. These requirements are ultimately determined based on the requirements of each resources company.

14.3 Demonstrator Project descriptions

Two Demonstrator Projects were commissioned to investigate the potential benefits of the SBAS signals to the resources sector and while these projects have been commissioned separately, the findings have been presented at a sector level.

Further details of these Demonstrator Projects are contained in Table RES1.

Table RES1 – Resources sector project descriptions

Demonstrator project	Description	Signals tested
Queensland University of Technology (QUT)/Wenco International Mining Systems (Wenco)	Exploring the benefits of the SBAS signals in relation to fleet management in the form of an enhanced collision avoidance system (CAS) within mines, improved haulage operations, and enhanced fleet telemetry.	L1, DFMC, PPP

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[264] Roarty, M (2010) The Australian resources sector, its contribution to the nation, and a brief review of issues and impacts. Retrieved from: https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/BN/ 1011/AustResources#_Toc273016102

[265] For example, Rio Tinto automated fleets have been reported as recording a 12 percent productivity improvement in comparison to manned fleets. Latimer, C (2015) Mining automation: The be all and end all? Retrieved from: https://www.australianmining.com.au/features/mining-automation-the-be-all-and-end-all/

Demonstrator project	Description	Signals tested
Curtin University/Roy Hill	Exploring the benefits of the SBAS signals in a mine environment with specific focus on exploratory operations, ore mapping, and management.	L1, DFMC, PPP

14.4 Anticipated benefits

A benefits mapping exercise was undertaken with each Demonstrator Project to identify how the benefits of the SBAS signals could flow through to operating changes in the future. This then led to the identification of the following potential operational benefits.

Reduced collisions via enhanced CAS

Open-pit mine sites across Australia and New Zealand have a significant number of haul trucks that frequently transport minerals from the pit to stockpiles or other locations. Overburden is also transported from mining sites to various other locations. This activity creates a risk of vehicle collisions on the mine site. Collisions in this instance can include[266] vehicle to vehicle, vehicle to person, vehicle to equipment, and vehicle to environment.

Many of these vehicles are currently fitted with CAS and it is anticipated that greater accuracy afforded by the SBAS signals will allow for the reduction of the size of collision avoidance buffer zones within mines thereby reducing the risk of false positives. This will then allow for greater confidence in CAS and reduce the likelihood of fatalities and serious injuries.

Reduction in vehicle downtime

In certain instances, vehicle-related accidents may not lead to serious harm or injury but still result in an out-of-commission vehicle. Every hour a vehicle is out of commission represents an hour of lost productivity and therefore a cost to the mining operator. A consequence of reduced collisions is the anticipated reduction in vehicle downtime across mines, resulting in an operational saving for mining operators.

Improved haul truck efficiency

The increased effectiveness of CAS is also anticipated to increase the efficiency of haul truck speeds within mines as drivers place greater faith in safety mechanisms. This is anticipated to result in a reduction in operating expenditure associated with fuel and labour costs.

Enhanced exploratory surveying efficiency

Exploration drilling is forecast to require less survey support as on-board guidance systems for drilling rigs can independently mobilise and confidently locate planned drill hole location, dip, and angle. This capability removes the need for surveyors to manually peg and re-peg drill hole locations.

Enhanced shovel productivity through enhanced ore mapping

Enabling geologists to accurately assess localised geological formations in the field and rapidly update geological modelling can support engineering teams in the optimisation of drill and blast parameters. This can lead to greater control over blast performance and the ability to effectively break up rock formations.

Research suggests that uniform fragmentation has a direct correlation to muck pile looseness (the waste material surrounding a drill point), which lends to improved ability to undertake digging activities and the extent to which shovels can be filled effectively. Subsequently, the loading time required to fill one mine haul truck to its targeted payload is reduced, leading to a direct increase in load unit productivity[267].

The SBAS signals have the potential to more accurately, and in real-time, assess localised geological formations which can improve the productivity benefits cited above.

Improved plant operating efficiency through better material management

Iron ore does not exhibit identical material characteristics across a mine site[268]. Ore is defined by the proportion of its content that is truly ore, but its characteristics can range significantly across a single operation depending upon the localised geological formations. For example, some ore may have a

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[266] EMESRT (2016) A ‘safety by design’ initiative operated by the global mining industry: vehicle interaction. Retrieved from: https://emesrt.org/wp-content/uploads/2016/05/EMESRT-VI-Master-Slides-07-04-2016-V5-1.pdf

[267] Orica Mining Services (n.d.) Improving fragmentation to drive shovel productivity and improve mill. Retrieved from: http://www.oricaminingservices.com/uploads/Fragmentation/open%20cut%20metals/100028_Case%20Study_Improving%20Fragmentation%20to%20Drive%20Shovel%20Productivity%20and%20Improve%20Mill%20Feed%20Gibraltar%20Mine_English.pdf

[268] This benefit category specifically relates to iron ore mining as opposed to other mining types.

high moisture content and be heavily mixed with clay, leading to a sticky composition. When this material is the sole source of feed for the processing plant it may significantly reduce the plant's throughput and operating efficiency.

Mine planning teams must work closely with plant metallurgists to plan feed sources effectively across the mine to balance out these unproductive characteristics. Shovel and loader operators play a critical role in ensuring ore sources are dug to plan.

Higher precision positioning combined with on-board visualisation systems for load unit operators, provides more accurate boundaries for ore types and waste contact within a dig site. This enables the production, planning, and processing teams to impose greater control over material feeds to the plant, allowing improved forecasting and optimisation of the ratio between material characteristics and plant controls, leading to improved operating efficiency and throughput rates.

Similar to the previous benefit, the SBAS signals have the potential to more accurately, and in real-time, assess localised geological formations which can improve the productivity benefits cited above.

Reduction in environmental incidents

A combination of accurate spatial mapping and hazard detection systems can potentially enable greater accuracy in the detection and mapping of environmentally sensitive areas within mines.

When a vehicle comes into close proximity of a sensitive area an alert system will notify the driver and minimise the risk of environmental harm resulting from accidents, i.e. vehicle traversing into habitat zones or protected vegetation.

Furthermore, the accurate mapping of sensitive areas would enable well-informed planning when it comes to mining operations, thereby reducing the overall environmental impact of the mining operation.

Improved loader and shovel availability through more timely location

Loaders are versatile dig units with a high level of mobility compared to track mounted shovels and excavators. This equipment is typically relocated multiple times throughout a shift to different dig faces, depending upon the ore blending requirements and truck allocations.

As loaders are less productive than primary dig units (shovels and excavators), this equipment will typically be parked at the end of a shift until an incoming crew locate it and re-start production (contrary to primary dig units which are manned until the operator can be immediately replaced).

Due to their mobile nature, this often results in loaders being parked in varying locations. This creates complications when incoming crews have insufficient handover information and can potentially result in a loss of productive operating hours as they spend additional time searching for its location.

Enhanced maintenance of vehicles and equipment

Maximising net available time of capital equipment is a prime objective of a mine site. Being able to quickly identify the location of capital equipment that breaks down on a mine site is one element to maximising equipment availability.

Installing tracking devices and location tags on all capital equipment (loaders, shovels, haul trucks, etc.) is one way of supporting faster identification of capital equipment and is commonplace within the industry. The sophistication of the positioning systems associated with these devices (and associated equipment) can vary depending on the nature of the equipment. For example, loaders may have high-precision GNSS associated with them, whereas shovels may have standalone GNSS.

The SBAS signals may provide some benefits for certain types of equipment in terms of faster location of idle equipment. This can lead to faster repairs and maintenance, greater overall utilisation of equipment, increased productivity, and lower operating costs.

Anticipated benefits for the resources sector have been classified into the benefit categories in Table RES2.

Table RES2 – Resources sector benefit categorisation

Benefit	Benefit category	Quantitative?
Reduced collisions via enhanced CAS	Health and safety	Yes
Reduction in vehicle downtime	Operating expenditure savings	Yes
Improved haul truck efficiency	Operating expenditure savings	Yes
Enhanced exploratory surveying efficiency	Operating expenditure savings	Yes

Benefit	Benefit category	Quantitative?
Enhanced shovel productivity through enhanced ore mapping	Operating expenditure savings	Yes
Improved plant operating efficiency through better material management	Operating expenditure savings	Yes
Reduction in environmental incidents	Environmental	No
Improved loader and shovel availability through more timely location	Operating expenditure savings	No
Enhanced maintenance of vehicles and equipment	Operating expenditure savings	No

14.5 Positioning needs and current methods

As mentioned earlier in the Chapter, there are no regulatory requirements when it comes to precision mining. Instead, discussion with the sector suggests that positioning accuracy requirements are driven by the manufacturers developing the equipment and mining companies within the sector.

14.5.1 Reduced collisions via enhanced CAS

Terminology around CAS varies significantly across regulatory bodies, original equipment manufacturers (OEM) and mining companies alike. For the purposes of this Chapter, Minetec's definitions[269] have been adopted which define CAS as using two separate systems:

Proximity detection system (PDS)

A PDS can detect vehicles and people within the vicinity of the enabled vehicle and register the event. The system is solely used for detection and alerts and does not take further action.

Vehicle control system (VCS)

A VCS can interact with the vehicle directly; however, it does not understand what is around the vehicle. It can read machine health and telemetry information such as vehicle speed and operating gear, and (in some vehicles) control the vehicle including idling the engine and applying brakes.

In tying these two systems back to CAS, a simplified view is that the PDS is responsible for *detection* of a hazard whilst the VCS is responsible for the *act of avoiding* a hazard. Based on this definition, enhanced spatial accuracy afforded by the SBAS signals are likely more relevant to the PDS component of a CAS. Therefore, an enhanced PDS leads to an enhanced CAS[270].

In practice, a CAS generates a radius around each vehicle, based on the vehicle size and time to collision. Figure RES4 has been provided by a Demonstrator Project and is a practical representation of what such a system looks like. It details when this area or buffer zone around a vehicle overlaps with another vehicle's buffer zone, the system alerts the driver to a potential hazard (as shown in the bottom of the two screens).

According to empirical research[271], the minimum time required by a driver to appropriately react and avoid a hazard is 700 milliseconds. According to information provided through consultation in preparing this Chapter, a reaction time buffer zone of 10 metres is therefore required. A radius less than 10 metres would provide too little time for the driver to react, whilst a radius greater than 10 metres would increase the likelihood of false positives and reduce the trust in the system.

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[269] Minetec (2017) Proximity detection and collision avoidance systems for dummies. Retrieved from: http://minetec.com.au/news/proximity-detection-collision-avoidance-systems-for-dummies/

[270] Minetec (2017) Proximity detection and collision avoidance systems for dummies. Retrieved from: http://minetec.com.au/news/proximity-detection-collision-avoidance-systems-for-dummies/

[271] Yang, B et al (2017) Influences of waiting time on driver behaviors while implementing in-vehicle traffic light for priority-controlled unsignalized intersections. Journal of Advanced Transportation. Volume 2017, Article ID 7871561.Retrieved from: http://downloads.hindawi.com/journals/jat/2017/7871561.pdf?bcsi_scan_01d939382f6c0b14=1

Figure RES4 – Example of CAS application

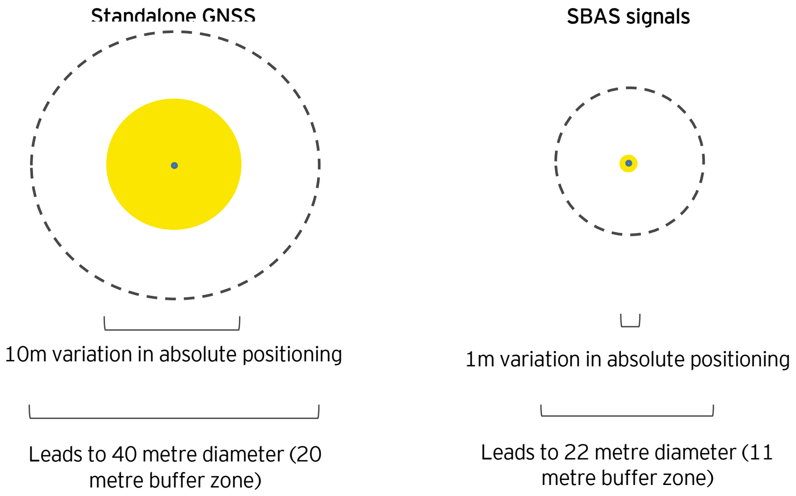
The sector currently utilises standalone GNSS for CAS, which provides a margin of error of approximately ± 10 metres according to testing in resources sector environments. This margin of error creates two issues relevant to health and safety risks.

First, it translates into a large buffer zone of 20 metres, which may unnecessarily capture hazards that pose no immediate threat to the vehicle. A 20-metre buffer zone is a result of the need for a reaction time buffer zone of 10 metres in addition to a GNSS error buffer zones of 10 metres.

Second, it means the system cannot accurately distinguish between two vehicles in close proximity of one another.

These risks are demonstrated in Figure RES5. The dot at the centre of the circles represents the vehicle. The yellow shaded area is the GNSS error margin (under a standalone GNSS and SBAS signal scenario) and the dotted line on the perimeter represents the total buffer zone incorporating GNSS error and the reaction time buffer.

Figure RES5 – Buffer implication from variation in absolute positioning



The larger buffer zone increases the likelihood of false positives, which consequently reduces trust in the system to the point where it could potentially be disabled by users. This presents a significant risk as vehicles are technically unprotected should they come across an actual hazard. The inability to distinguish between vehicles means that there is limited protection for two vehicles in close proximity to each other.

Of particular importance for CAS, is the need for the SBAS signals to provide sub-metre absolute positioning, which, as illustrated by Figure RES5, reduces the buffer area to a more desirable 11-metre radius.

By achieving an 11-metre buffer zone, CAS can offer a high level of safety whilst significantly reducing the likelihood of false positives, leading to the enhanced trust in the system, and therefore increased uptake. An 11-metre buffer zone in this instance refers to the GNSS error of sub-metre plus the 10-metre reaction time buffer required.

14.5.2 Reduction in vehicle downtime, improved haul truck efficiency and reduction in environmental incidents

The extent of reduction in vehicle downtime benefits, improved haul truck efficiency, and reduction in environmental incidents is tied to the improved performance of CAS, and as such, adopts the same sub-metre level positioning requirement (and status quo) as described in the reduced collisions via enhanced CAS description above.

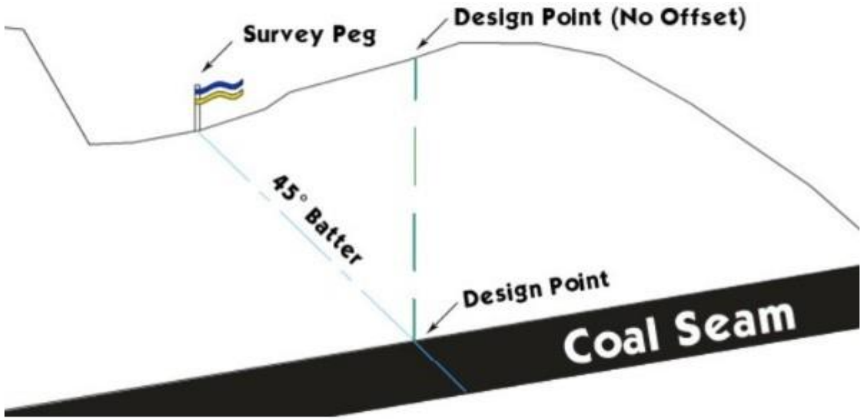
14.5.3 Enhanced exploratory surveying efficiency

Surveying forms a critical part of mining operations. A key step in the mine surveying process is the act of using physical pegs to demarcate drill-hole locations and to serve as a point of reference for excavation and blasting[272].

Identification of borehole locations is important during the exploratory phase of mining. At each borehole site, solid rock core, or rock chips (cuttings) are brought to the surface for examination, which then help operators establish the location of mineral deposits, which in turn guide the location and nature of excavation[273].

The location of boreholes is also used to establish additional survey pegs which are used as points of reference for battered excavation (see Figure RES6)[273]. In simple terms, pegs need to be placed at a projected position so if a machine digs from them at the design batter angle, it will end up at its desired location.

Figure RES6 – Example of battered excavation using survey peg

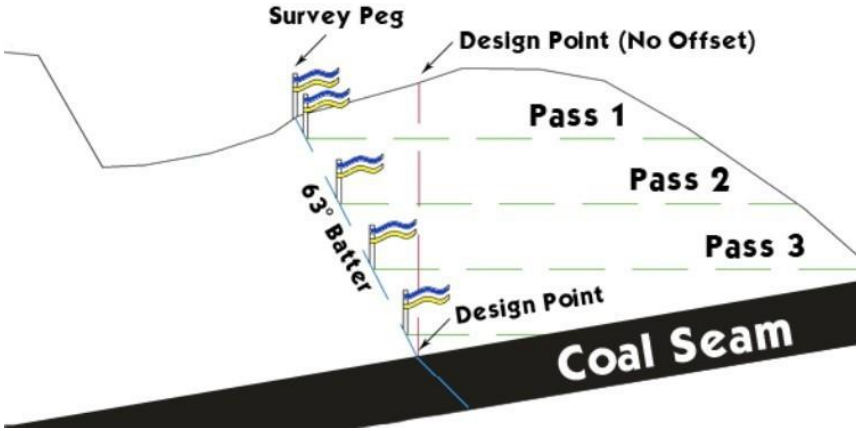


Currently, the primary means of positioning is via manual pegging. Not only is this process labour and time intensive, but pegs can be lost during site clearance, thereby requiring teams to go out and re-peg survey pegs.

This challenge can be overcome via digital pegging, which requires GNSS positioning. Standalone GNSS is considered unsuitable because the associated margin of error means operators run the risk of missing design points, i.e. points at which they want to enter an ore seam. This problem can be further compounded in situations which require multiple passes, as demonstrated in Figure RES7[274].

Based on discussion with the sector, an acceptable margin of error for the positioning of digital pegs is ± 20 centimetres.

Figure RES7 – Example of battered excavation over multiple passes



14.5.4 Enhanced shovel productivity through enhanced ore mapping and improved operating efficiency through better material management

The positioning requirements of enhanced shovel productivity through enhanced ore mapping and improved operating efficiency through better material management have been combined in this instance given that they rely on the same positioning requirements.

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[272] Mine surveyor (n.d.) Machine control (open-cut mine surveying duties). Retrieved from: http://www.minesurveyor.net/ssmachine.php

[273] New Zealand Petroleum and Minerals (2018) Phases of mineral exploration and production. Retrieved from: https://www.nzpam.govt.nz/our-industry/nz-minerals/phases/

[274] Mine surveyor (n.d.) Machine Control (Open-cut Mine Surveying Duties). Retrieved from: http://www.minesurveyor.net/ssmachine.php

Geologists typically perform field mapping of geological structures prior to drilling and blasting, to determine material types and feed this information to engineering teams.

Accurate mapping is often difficult if survey teams are busy with other tasks and geologists rely on rough sketches, consumer grade GNSS receivers, and estimated boundaries. SBAS will potentially enable quick and accurate geological mapping, which can be rapidly converted into geological models, providing higher resolution for drill and blast design parameters and blast performance. Greater blast control and uniform rock fragmentation would lead to better digging conditions and an improvement in equipment productivity.

Any improvement on the status quo (accuracy and reduced impact of reduced signal coverage) provided by the SBAS signals will support improvements in productivity noted above.

14.5.5 Improved loader and shovel availability through more timely location of assets and enhanced maintenance of vehicles and equipment

Currently capital equipment can be located with location tags and standalone GNSS and greater accuracy is not always required to locate a vehicle. Moreover, equipment with a higher level of importance on-site often utilises precise positioning as the need to monitor location of this equipment at all times is paramount. The faster location of equipment means it can be located, repaired, and maintained more quickly which gives it a higher utilisation rate.

However, there are certain instances where greater signal coverage from the SBAS signals could be an improvement on the status quo. These include instances where equipment is near a mine face or other obstructions that limit the visibility of relevant constellations.

14.6 Sector benefits

The following sections detail the benefits of SBAS relative to the status quo, describe the anticipated economic impact, and estimate how benefits are attributed across the three signals.

Unlike many other sectors represented in the Demonstrator Trial, the difference in scale between the Australia and New Zealand resources sector remains quite significant and disproportionate to differences in population. The end outcome of this analysis is that economic benefits of the SBAS signals that accrue to the resources sector are heavily skewed towards Australia.

14.6.1 Signal attribution

Table RES3 contains details around the expected performance of the SBAS signals within the resources sector. As mentioned throughout this Chapter, when it comes to positioning requirements, some benefits are contingent on certain accuracy thresholds being met, whilst other benefits improve as positioning accuracy increases.

These indicative test results have been provided by FrontierSI as representative results of the testing carried out by the SBAS Demonstrator Projects in this sector. The testing was carried out in lightly to partially obstructed environments with mid-range and professional equipment. Values presented are 95 percent confidence interval.

For the avoidance of doubt, horizontal positioning is required in most cases, although some benefits also profit from vertical positioning information and these are described where relevant.

Table RES3 – Resources sector signal attribution

Signal	Resources sector test results	
	Expected horizontal performance (m)	Expected vertical performance (m)
L1	0.9	2.7
DFMC	0.6	2.0
PPP	0.2	0.7

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Quantitative benefits					
Reduced collisions via enhanced CAS	Sub-metre	100%	100%	-	PPP unlikely to be used due to receiver cost
Reduction in vehicle downtime	Sub-metre	100%	100%	-	PPP unlikely to be used due to receiver cost
Improved haul truck efficiency	Sub-metre	100%	100%	-	PPP unlikely to be used due to receiver cost
Enhanced exploratory	Decimetre	-	-	100%	Decimetre accuracy required

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
surveying efficiency					
Enhanced shovel productivity through enhanced ore mapping	Variable	90%	90%	100%	Improved accuracy of ore mapping will occur incrementally to PPP
Improved plant operating efficiency through better material management	Variable	90%	90%	100%	Improved accuracy of ore mapping will occur incrementally to PPP
Qualitative benefits					
Reduction in environmental incidents	Sub-metre	✓	✓	-	PPP unlikely to be used due to receiver cost
Improved loader and shovel availability through more timely location	Variable	✓	✓	✓	Different equipment will benefit from different signal types
Enhanced maintenance of vehicles and equipment	Variable	✓	✓	✓	Different equipment will benefit from different signal types

14.6.2 Uptake rate

An S-curve uptake curve has been deployed for all benefits in the resources sector. This reflects discussion with the sector which suggests slow initial uptake reflected by early adopters, followed by exponential uptake as the majority of the market follows suit and a steady plateau in the long-run.

14.6.3 Quantitative benefits

An important limitation to the SBAS signals in the resources sector is that it is only effective in open-pit mines, not those underground. Sixty percent of mines in the sector across both Australia and New Zealand are open-pit mines, according to discussions with the sector.[275]

It is further understood from discussions with the sector that this proportion is anticipated to increase, with the expectation that no (or very few) new underground mines will be created over the coming decades – although this proportion has not been altered in the economic modelling as there is not a high level of confidence at the rate in which this proportional split will change over time.

14.6.3.1 Reduced collisions via enhanced CAS

Over a 30-year assessment period, it is anticipated that a total of three fatalities will be avoided in open pit mines directly attributable to the SBAS signals, via implementation of enhanced CAS, resulting in an economic saving of PV$3m. This benefit is solely attributable to Australia given the low frequency of similar events in New Zealand.

A key challenge in the quantification of this benefit was understanding the impact of a CAS on vehicle-related incidents within mines. The proxy utilised to determine this impact was driver inattention, which suggests that 11.7 percent of incidents over the 30-year period would be attributable to driver inattention, which could be avoided using a CAS.

A study[276] used a sample of 856 crashes from the Australian National Crash In-Depth Study to investigate the role of driver distraction and inattention in serious casualty crashes.

In attempting to determine whether inattention was involved in a particular crash, the researchers demarcated five sub-types of inattention:

- Restricted attention due to physical and biological factors
- Mis-prioritised attention excessively focussed on less safety-critical aspects of driving
- Neglected driver fails to attend to activities critical for safe driving
- Cursory driver attends superficially to activities critical for safe driving

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[275] It is also worth reiterating that the New Zealand and Australian resources sectors differ markedly and this has implications for scaling decisions. These are described throughout the text and in the assumptions and limitations section of this Chapter (14.8).

[276] Beanland et al (2013) Driver inattention and driver distraction in serious casualty crashes: Data from the Australian national crash in-depth study. Accident Analysis & Prevention, Volume 59, October 2013, Pages 626. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S000145751300047X

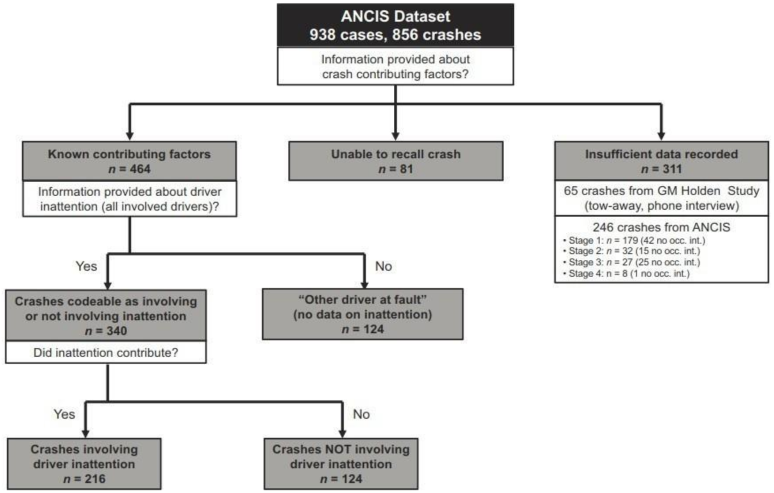
- Diverted driver's attention is diverted to an activity that is not critical for safe driving.

Of the five sub-types of inattention identified, it is assumed that driver restricted attention stands as the sole sub-type not to benefit from an effective CAS as the driver would likely not be able to recognise the alert let alone respond to it. Driver restricted inattention includes a range of sub-categories such as being intoxicated, blacking-out, falling asleep, feeling ill, having a seizure, and feeling fatigued.

Further calibration of the analysis was undertaken whereby several of these sub-categories were re-included in the total ('feeling ill' and a proportion of 'fatigued') as it is expected that drivers under these conditions would be able to respond to collision alerts. This calibration eventually resulted in 116 of the 216 events (noted in bottom left box of the flowchart in Figure RES8) being removed as irrelevant to the analysis.

The resulting 100 incidents taken as a portion of total crashes recorded resulted in 11.7 percent of total crashes potentially being attributable to the SBAS signals. Given that the purpose of the CAS is to avoid fatal accidents due to inattention, it is noted that the empirical research serves as a sufficient proxy.

Figure RES8 – Driver inattention proportionality



A key point to note is that the reduction in fatalities is not solely due to increased uptake of CAS, but rather due to better utilisation of CAS resulting from greater trust in the system. For example, it is acknowledged that some vehicles involved in fatal accidents have CAS installed, but have them switched off, whereas improved confidence in the system would encourage users to leave it switched on, leading to accidents being avoided.

The total number of fatalities avoided due to the SBAS signals has then been multiplied by a value of life figure and adjusted for uptake and inflation to arrive at a final economic benefit as shown in Table RES4.

Table RES4 – Avoided fatality calculation (30-year calculation)

Factor	Value	Notes
Total open-pit mine production	32,000m tonnes	Total mine production (based on top seven mineral exports) across Australia over 30 years
Total vehicle-related mining fatalities	48	Derived 671 mega tonnes per vehicle-related fatality, per annum
Anticipated fatalities avoided due to enhanced CAS	6	Assuming 11.7% of fatalities are due to avoidable inattention
Adjusted for uptake	3	S-curve over 30 years
Value of fatalities avoided	$10.5m	Based on value of life figure of $3.45m
Present value	$3m	Discounted at 6.5%

Note: Totals may not sum due to rounding

With regards to serious injuries, data available at the national level does not suggest that serious injuries pertaining to vehicle accidents are a materially significant feature of the resources sector.

The most comprehensive dataset available that records injuries is from the 2011-12 Traumatic Injury Fatalities Database[277]. The database uses serious

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[277] Safework Australia (2012) Mining. Retrieved from: https://www.safeworkaustralia.gov.au/system/files/documents/1702/mining-fact-sheet-2011-12.pdf

claims as the form of measure of injury. Serious claims are defined as successful worker's compensation claims for serious injury or illness.

According to the database, during 2011–12, there were 3,365 claims in the resources sector. The data implies that the primary causes for these claims were body stressing (34 percent); falls, trips, and slips of a person (22 percent); and being hit by a moving object (18 percent). Collectively these account for almost 75 percent of all claims[278].

Vehicle accidents were not recognised as a major source of serious injury (the moving object primarily referred to metal objects such as pipes, bars, beams or rocks, stones, and boulders).

Given the insignificance of serious injuries resulting from vehicle accidents, along with a mining workforce that is likely not to substantially increase as technological productivity places downward pressure on employment numbers, it is assumed that the total number of serious injuries associated with vehicle collisions will probably be immaterial.

Nevertheless, it is likely that CAS will reduce the risk of vehicle-to-vehicle accidents, thereby reducing the risk of these serious injuries.

14.6.3.2 Reduction in vehicle downtime

Over a 30-year assessment period, it is anticipated that a total of 205,000 hours of collision-related vehicle downtime will be avoided due to an SBAS signal-enhanced CAS system. This is anticipated to generate a PV$130m saving to the resources sector across Australia and New Zealand.

Discussion with the sector suggested that on average, a mine has one haul truck out of commission per month, totalling 12 vehicles per annum. This factor was applied to the total number of open-pit mines across Australia and New Zealand[278] to arrive at the total number of decommissioned vehicle events per annum. It is further assumed that 50 percent of decommissioned vehicle events are due to collisions.

It is also assumed that for each decommissioned vehicle event, the vehicle is out of action for a full day, which equates to 18 operational hours.

A Demonstrator Project has advised that a reasonable industry average for each hour that a haul truck is out of commission is $2,300. This is value that is lost to the company that owns and operates the haul truck.

The anticipated benefit of reduced collision-related vehicle downtime from utilisation of SBAS signal-enhanced CAS has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table RES5.

Table RES5 – Reduced vehicle downtime (30-year calculation)

Factor	Value	Notes
Total decommissioned vehicle events	45,350	Cumulative total over 30-year period (assuming one event per month per relevant mine)
Total decommissioned vehicle events due to vehicle collisions	22,700	Assuming 50% of total events due to vehicle collisions
Total decommissioned hours	410,000 hours	Based on 18 hours of downtime per decommission event
Gross value of decommissioned hours	205,000 hours	S-curve over 30 years
Gross saving	$470m	Operational cost of $2,300 per decommission hour
Present value	$130m	Discounted at 6.5%

Note: Totals may not sum due to rounding

14.6.3.3 Improved haul truck efficiency

More efficient haul truck speeds resulting from greater confidence in CAS is anticipated to generate PV$577m worth of savings to the sector over a 30-year period within open-pit mines.

The central concept at the heart of this benefit is the idea of vehicle operating costs (VOC). In simple terms, the VOC represents the basic operating cost of a vehicle per km travelled and comprises running costs, road surface related

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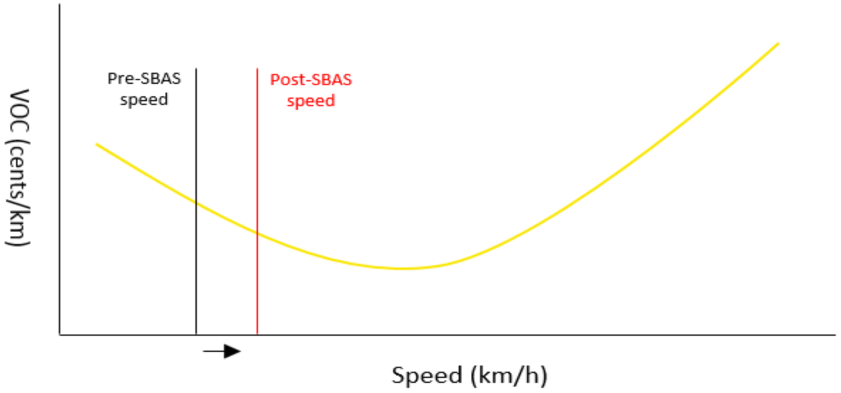
[278] The top seven producing mineral types in Australia have been used as a basis for calculating this figure. These are: iron ore, coal, copper, aluminium, zinc, nickel, and lead.

costs, speed change cycle costs, congestion costs, and costs while at a stop[279].

Research suggests that at lower speeds, the VOC remains high due to inefficient movement relative to minimum fuel requirements to keep the car engine running. As speeds increase, a vehicle moves more efficiently relative to the fuel burned, which sees a decrease in VOC. After a certain point, however, VOC again starts to rise due to the effects of increasing aerodynamic drag[280]. As the specific shape of this curve will be vehicle dependent, this relationship is demonstrated stylistically in Figure RES9.

Figure RES9 – Stylistic representation of the VOC correlation to speed



It is assumed that a five kilometre per hour increase in speed across the entire haul truck fleet is possible with the SBAS signals, as a result of greater confidence in the position of a haul truck in relation to other vehicles, hazards, and objects. A five kilometre per hour increase in speed equates to a 1.2 percent decrease in VOC. This proportional saving has been applied to total haul truck fuel costs and labour costs to arrive at the potential operational saving.

To determine fuel cost savings, total fuel consumption across the Australia and New Zealand haul truck fleet (of approximately 5,700 haul trucks[281]) was first established. This was done by applying average fuel consumption rates in litres an hour of 180 (high load), 140 (medium load) and 100 (low load) to total operational hours across all fleet trucks. These rates have been determined from advice from a Demonstrator Project[282].

Based on similar advice from a Demonstrator Project, all mines have been assumed to use Caterpillar 789D haul trucks and operate at high load 50 percent of the time, medium load 10 percent of the time and low load 40 percent of the time.

The 1.2 percent VOC saving was then applied to total fuel consumption and then multiplied by a per litre fuel cost of $1.40 to arrive at a total gross saving of $5m.

To determine labour cost savings, an average labour cost of $40 per hour[283] was divided by average speed to identify the per kilometre labour cost. This was then applied to total distance travelled across the entire haul truck fleet, assuming average speeds of 30 kilometre per hour over 18 hours a day, 350 operational days per annum. This provided the total labour cost for haul truck drivers ($1.30 per kilometre travelled) to which the 1.2 percent VOC saving was applied.

The anticipated benefit of more efficient haul truck movement from utilisation of SBAS signal-enhanced CAS has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table RES6.

Table RES6 – Improved haul truck efficiency (30-year calculation)

Factor	Value	Notes
	Fuel savings	
Total fuel consumed	204b litres	5,700 haul trucks 350 days operation 18-hour day operation Fuel consumption rates as per text

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[279] New Zealand Transport Agency (2016) Economic evaluation manual. Retrieved from: https://www.nzta.govt.nz/assets/resources/economic-evaluation-manual/economic-evaluation-manual/docs/eem-manual-2016.pdf

[280] New Zealand Transport Agency (2016) Economic evaluation manual. Retrieved from: https://www.nzta.govt.nz/assets/resources/economic-evaluation-manual/economic-evaluation-manual/docs/eem-manual-2016.pdf. Refer to tables A5.1 to A5.10

[281] The Parker Bay Company (2019) Mining trucks. Retrieved from: http://parkerbaymining.com/

[282] Caterpillar (2016) Caterpillar performance handbook. Retrieved from: https://www.williamadams.com.au/media/1769/caterpillar-performance-handbook-46.pdf

[283] Indeed (2019) WorkPac dump truck driver hourly salaries in Australia. Retrieved from: https://au.indeed.com/salaries/Dump-Truck-Driver-Salaries-at-Workpac

Factor	Value	Notes
Fuel consumption saving per annum	2.38b litres	Applying 1.2% VOC saving
Fuel saving	1.3b litres	S-curve over 30 years
Gross value of fuel saving	$1.81b	Based on $1.4 per litre
Labour savings		
Total labour cost across all haul trucks	$57b	Based on per km labour cost of $1.30
Labour cost saving	$661m	Applying 1.2% VOC saving
Gross value of labour saving	$360m	S-curve over 30 years
Total gross value	$2.17b	Fuel and labour cost savings
Present value	$577m	Discounted at 6.5%

Note: Totals may not sum due to rounding

14.6.3.4 Enhanced exploratory surveying efficiency

SBAS signal-enabled operating costs savings associated with surveying activities in the iron ore sub-sector is anticipated to generate PV$6m worth of savings to the sub-sector over a 30-year period.

A Demonstrator Project has advised that pre-SBAS operating methods typically 0.3 FTE hours per annum to manually peg and re-peg drill hole locations in given exploration sites.

It is estimated that this entire activity could be replaced by SBAS-enabled applications as drill rig on-board guidance systems could independently mobilise and confidently locate planned drill hole locations (amongst other things). The average annual salary of a comparable occupation category[284] has been used as a proxy for the value that can be freed up by relying on SBAS-enabled applications.

These inputs have then been multiplied by the estimated number of iron ore mines across Australia[285] to determine a sub-sector wide operational efficiency calculation.

The anticipated total operating expenditure reductions associated with the SBAS signals have then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table RES7.

Table RES7 – Enhanced exploratory surveying efficiency (30-year calculation)

Factor	Value	Notes
Total number of iron ore mines	44	This count only applies to Australia Future iron ore mine counts have been held constant throughout the modelling period
Total labour savings	396 FTE	Total FTE saving across 44 mine sites over 30 years.
Value of labour savings	$43.8m	Based on comparable industry salary of $110,000 per annum
Adjusted for uptake	$21.8m	S-curve over 30 years
Present value	$6m	Discounted at 6.5%

Note: Totals may not sum due to rounding

14.6.3.5 Enhanced shovel productivity through enhanced ore mapping

SBAS signal-enabled operating costs savings associated with enhanced fragmentation activities in the iron ore sub-sector is anticipated to generate PV$229m worth of savings to the sub-sector over a 30-year period.

This calculation methodology is based on hydraulic shovel loading time savings associated with drill and blast and load and haul operating procedures.

To understand the potential improvements, a baseline level of activity was first required. Key assumptions in determining this baseline include:

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[284] Infomine (n.d.) Mining Labor compensation surveys: mine wages and benefits. Metal, coal and industrial mineral mines. Retrieved from: http://costs.infomine.com/costdatacenter/miningwagesbenefits.aspx

[285] Department of Industry, Innovation and Science (2018) Resources and energy quarterly. Retrieved from: https://publications.industry.gov.au/publications/resourcesandenergyquarterlyseptember2018/documents/Resources-and-Energy-Quarterly-September-2018-Iron-Ore.pdf

Defining the equipment affected

It has been assumed that a 30 cubic metre capacity hydraulic shovel matched with a CAT 793 haul truck with a 220-tonne payload would be affected.

Determining current loading times

Benchmarking analysis[286] suggests an average productivity of 3,442 tonnes per operating hour, when time taken for trucks to orientate into position is removed, overall loading time is estimated to be 3.3 minutes.

Discussions with a Demonstrator Project have then helped validate the potential load time improvements associated with SBAS-enabled activity. The two core assumptions that have been included in the modelling are:

- Hydraulic shovel loading times were conservatively estimated to be improved by five percent.
- SBAS contribution was limited to three percent.

This results in an assumed SBAS-enabled productivity improvement weighting of 0.15 percent to shovel loading activities.

This inherently acknowledges that SBAS and geological modelling is a relatively small enabler in a series of larger improvement requirements within drill and blast, and load and haul operating procedures, such as fragmentation modelling, blast pattern calibration, fragmentation measurement, and operator training).

When coupled with assessments of current shovel utilisation and availability, and an assumed ability to reduce average loading time by 30 seconds, this leads to an annual shovel productivity increase of 0.13 percent (or 25,800 tonnes per shovel, per annum).

This calculation has then been incorporated into assessments of average number of shovels per operation per mine[287], average strip ratio per mine[288], and total number of operative mines[289] to arrive at an initial production increase.

A long-term view about the value of iron ore has then been applied to determine the initial value generated from this activity[290].

It is acknowledged that mining operators will face a choice about producing more iron ore or reducing operating costs. It has been assumed that the ability to produce materially more iron ore will eventually be capped – as mines operate under production limits – but the additional value of iron ore produced has been used as a proxy for the reduced operating costs.

The anticipated total operating expenditure reductions associated with the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic benefits shown in Table RES8.

Table RES8 – Enhanced shovel productivity (30-year calculation)

Factor	Value	Notes
Total number of iron ore mines	44	This count only applies to Australia Future iron ore mine counts have been held constant throughout the modelling period
National shovel production increase from SBAS-enabled activities	115m tonnes	Annual single shovel production increase (0.13%) 3.4 shovels per operation
Increased iron ore production	23m tonnes	Assumed strip ratio of 5:1
Value of increased iron ore production	$1.66b	A US$51 per tonne of iron ore estimate has been assumed. AUD:USD long-run exchange rate of 1.4 has then been employed.
Adjusted for uptake	$828m	S-curve over 30 years
Present value	$229m	Discounted at 6.5%

Note: Totals may not sum due to rounding

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[286] EY benchmarking data

[287] An EY-derived estimate. A Demonstrator Project has advised that this is a reasonable industry average.

[288] A Demonstrator Project has advised that this is a reasonable industry average. Some mining operations may have a strip ratio of 3:1, but other (particularly small) operators may have ratios much higher than 5:1. Strip mining ratio refers to the overburden to ore ratio of material extracted.

[289] Department of Industry, Innovation and Science (2018) Resources and Energy Quarterly. Retrieved from: https://publications.industry.gov.au/publications/resourcesandenergyquarterlyseptember2018/documents/Resources-and-Energy-Quarterly-September-2018-Iron-Ore.pdf

14.6.3.6 Improved plant operating efficiency through better material management

SBAS signal-enabled operating costs savings associated with improved material management activities in the iron ore sub-sector is anticipated to generate PV$636m worth of savings to the sub-sector over a 30-year period.

As noted earlier, iron ore is defined by its iron content, usually represented as a percentage of total volume, but its characteristics can range significantly across a single operation depending upon the localised geological formations.

Higher precision positioning combined with on-board visualisation systems for load unit operators, provides more accurate boundaries for ore types and waste contact within a dig face. This enables the production, planning, and processing teams to impose greater control over material feeds to the plant, allowing improved forecasting and optimisation of the ratio between material characteristics and plant controls, leading to improved operating efficiency and throughput rates.

Discussions with a Demonstrator Project have helped validate the potential improvements associated with SBAS-enabled activity. The two core assumptions that have been included in the modelling are:

- Operating efficiencies associated with the delineation and extraction of feed sources were conservatively estimated to be potentially improved by five percent.
- SBAS contribution to this benefit was then estimated to be five percent. This was the lower bounds of a five to ten percent range provided by a Demonstrator Project.

These Demonstrator Project-derived assumptions result in a SBAS-enabled productivity improvement attribution factor of 0.25 percent. This (comparably small) attribution factor implicitly recognises that SBAS is an enabler within a broad series of improvements that would be needed to make this benefit come to fruition.

This operating efficiency premium can then be applied to all output from a given mine site to understand the total output increase that is possible. Specifically, it is assumed that an average single site produces 7,285 tonnes per hour. This has been derived from a combination of EY benchmark data as well as public information about current output and capacity from various iron ore mine sites in Australia.

A long-term view about the value of iron ore has then been applied to determine initial value that is generated from this activity[290].

The anticipated total operating expenditure reductions associated with the SBAS signals have been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table RES9.

Table RES9 – Improved plant operating efficiency (30-year calculation)

Factor	Value	Notes
Total number of iron ore mines	44	This count only applies to Australia Future iron ore mine counts have been held constant throughout the modelling period
Total iron ore production (capacity)	25.74b tonnes	Assumed 19.5m tonne capacity per mine, per year
National iron-ore production increase from SBAS-enabled activities	64.35m tonnes	Annual plant efficiency increase (0.25%) Resulting in 21 tonnes per hour efficiency throughput
Value of increased iron ore production	$4.6b	A USD $51 per tonne of iron ore estimate has been assumed. AUD:USD long-run exchange rate of 1.4 has then been employed.
Adjusted for uptake	$2.3bm	S-curve over 30 years
Present value	$636m	Discounted at 6.5%

Note: Totals may not sum due to rounding

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[290] Department of Industry, Innovation and Science (2018) Resources and Energy Quarterly. Retrieved from: https://publications.industry.gov.au/publications/resourcesandenergyquarterlyseptember2018/documents/Resources-and-Energy-Quarterly-September-2018-Iron-Ore.pdf

14.6.4 Qualitative benefits

14.6.4.1 Reduction in environmental incidents

It is possible to create exclusion zones around sensitive environmental areas. This then helps to inform and alert mine operators, vehicle drivers, etc. about those areas which should not be encroached upon.

This practice is common in land use development plans, offshore oil and gas maps, and onshore mineral and mining activity. However, the real benefit involves the alignment of these static maps and integrating them with CAS, thereby turning the map from a static map to a dynamic environmental management tool for mine operators.

Discussion with the sector suggests the economic benefits associated with reduced environmental accidents are likely to be minimal, given the lack of sensitive environmental areas in and around the majority of Australia's mines. The same logic holds true for the New Zealand sector.

14.6.4.2 Improved loader and shovel availability through more timely location

As loaders are less productive than primary dig units (shovels and excavators), this equipment will typically be parked at the end of shift until an incoming crew locate it and re-begin production (contrary to primary dig units which are manned until the operator can be immediately replaced).

Due to their mobile nature, loaders are often parked in varying locations. This creates complications when on-coming crews have insufficient handover information, or loaders are located in positions that do not have clear lines of sight to relevant constellations, and results in a loss of productive operating hours as crews spend additional time searching for the loaders' locations.

Whilst it is difficult to quantify, if an assumption of a time saving of one minute per shift is made, this can translate to a 0.1 percent increase in secondary loader utilisation and a gain of 35.4 productive operating hours per annum. It is assumed that this benefit is only applicable to a single loader per iron ore operation, as most equipment is generally located with relative ease.

It has not been possible to determine the precise time savings for this benefit category as each unit will have very different receivers meaning that the time saving benefits will differ substantially across mines. However, a 35-hour operating saving per loader is a significant saving across 44 iron ore mines in Australia.

14.6.4.3 Enhanced maintenance of vehicles and equipment

Faster location of idle equipment and enhanced maintenance will allow for greater overall utilisation of equipment, leading to increased productivity and lower operating costs.

According to mining experts, this technology could lead to an increase of 10 to 20 percent in overall equipment availability, which is significant when compared to the current equipment availability rates of 50 to 70 percent.

14.7 Summary

Table RES10 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning. The quantifiable economic impact of L1, DFMC and PPP in the resources sector is anticipated to be **PV$1.58b** over a 30-year period.

Table RES10 – Benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Reduced collisions via enhanced CAS	Sub-metre	Standalone GNSS which creates false positives	Three fatalities are avoided resulting in $3m saving	L1, DFMC
Reduction in vehicle downtime	Sub-metre	Standalone GNSS which creates false positives	205,000 hours of haul truck vehicle downtime avoided resulting in saving of $130m	L1, DFMC
Improved haul truck efficiency	Sub-metre	No status quo. Benefit contingent on CAS effectiveness	$577m saving in haul truck operating expenditure from enhanced speeds	L1, DFMC
Enhanced exploratory surveying efficiency	Decimetre	Use of survey teams for pegging and re-pegging activity	$6m worth of savings to the sub-sector from real-time surveying activities	PPP
Enhanced shovel productivity through	Variable	Combination of manual processes and	Enhanced fragmentation activities in the iron	L1, DFMC, PPP

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
enhanced ore mapping		augmented GNSS	ore sub-sector can generate $229m worth of savings.	
Improved plant operating efficiency through better material management	Variable	Combination of manual processes and augmented GNSS	Improved material management activities in the iron ore sub-sector can generate $636m worth of savings	L1, DFMC, PPP
Reduction in environmental incidents	Sub-metre	Currently mapped and monitored manually	Creation of exclusion zones around sensitive areas	L1, DFMC
Improved loader and shovel availability through more timely location of assests	Variable	Combination of standalone and augmented GNSS	Reduced loader and shovel downtime resulting in operating expenditure savings	L1, DFMC, PPP
Enhanced maintenance of vehicles and equipment	Variable	Combination of standalone and augmented GNSS	Potentially an increase of 10-20% in overall equipment availability	L1, DFMC, PPP

A range of additional applications in the resources sector have been identified throughout this research but have not been quantified (or described qualitatively) for a range of reasons[291]. A collection of these applications is provided in the additional applications Chapter 18.

14.8 Assumptions and limitations

The economic modelling undertaken for this sector has been based on a combination of official data sources, desktop research, information provided by the Demonstrator Project as well as rational and logical assumptions. These assumptions have all been agreed in discussion with the relevant Demonstrator Project and FrontierSI.

In addition to standard caveats around economic modelling, the following assumptions and limitations are worth highlighting:

Present value discount

All quantitative benefits have been discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

Attribution for enhanced CAS

Assumed that 100 percent of defined health and safety benefits derived from enhanced CAS is attributable to the SBAS signals due to its ability to augment an existing technology.

Attribution for haul truck efficiency

A 25 percent attribution rate has been applied to the haul truck efficiency benefit defined in acknowledgement of other factors which will play a role in improved speeds such as road type, regulation, and driver capability.

Total haul trucks

Using data provided by The Parker Bay Company, there are 5,526 haul trucks in Australia from the major manufacturers (Caterpillar, Komatsu, Liebherr, Hitachi, Terex, Volvo) that were manufactured in the last 20 years.

Trucks older than 20 years-old have been excluded because their technology and capacity would be limited.

Australian and New Zealand open-pit market share

Assumed to be 60 percent based on a count of Australian mine types.

It is worth reiterating that the New Zealand and Australian resource sectors are very different in size, scale, and nature.

The benefits in this Chapter have been based on Australian mining examples and then scaled across to New Zealand. In practice, it is possible that the benefits presented in this Chapter may undercount the benefits to New Zealand given that only the largest five mines in New Zealand were used as comparators. It is also possible that these benefits may overcount given the

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[291] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

size, value, and nature of capital equipment in Australia in comparison to New Zealand.

Australian resources sector growth rate

Assumed to be two percent p.a. over 30 years. This is based on historical averages.

New Zealand resources sector growth rate

Assumed to be negative one percent p.a. over 30 years. This is based on historical averages.

Haul truck operations

Mines are assumed to possess a haul truck for every 0.11m tonnes processed. This assumption is based on roughly 18 operational hours a day, 350 days a year.

Road sector

Key findings

The road sector focuses exclusively on private, public, and commercial vehicles on urban and rural road networks. Significant technological improvements over the last decade, such as increasingly automated vehicles, have enhanced the performance of the sector and it is likely that the SBAS signals will have a role in continued sector transformation.

Highlights

The SBAS signals are anticipated to generate a **PV AUD$1.1b** economic impact across the Australian and New Zealand road sector over a 30-year period. A selection of these benefits consists of:

- 75m hours of productive travel time anticipated to be saved via SBAS signal-enabled connected and automated vehicles (CAVs) and co-operative intelligent transport system (C-ITS) signal priority applications resulting in a **PV$760m** economic productivity improvement for the sector over 30 years.
- 45 road-related fatalities and 2,800 road-related serious injuries avoided via SBAS signal-enabled C-ITS resulting in **PV$277m** worth of savings to the sector over 30 years.
- The SBAS signals might facilitate greater transition from manual road user charges (RUC) licenses to electronic RUC (eRUC) systems which can reduce administrative costs for government and users.

Quantifiable benefits

Figure RO1 - Benefits by benefit category (30-year, AUD)

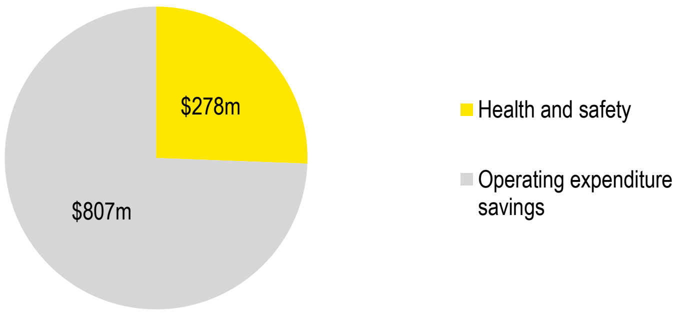


Figure RO2 – Benefits by geography (30-year, AUD)

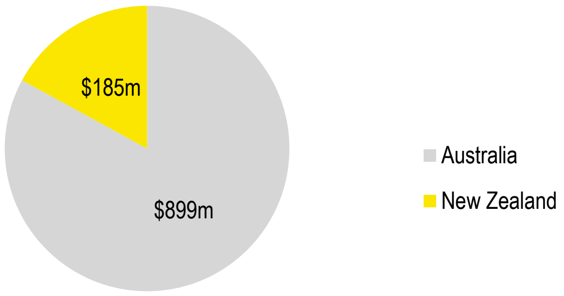
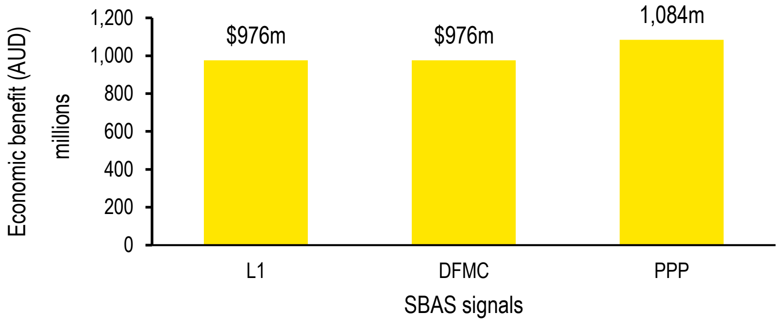


Figure RO3 – Benefits by signal type (30-year, AUD)



15. Road sector

15.1 Sector description

The modern-day road network is increasingly reliant on positioning technology, whether it is used for the creation of road maps, satellite navigation for vehicles, or for tracking public transport.

The road sector is large, and the public has a high level of user interaction. Road sector users consist of private, public, and commercial vehicles on both the urban and rural road networks.

The road sector plays a vital role in linking communities and regions within a country. It serves as a pathway to both social and cultural wellbeing, by improving the mobility and accessibility of people, playing a pivotal role in economic productivity, moving freight from factories to ports, and by moving people to their jobs. Given its strategic importance to the economy, it is of no surprise that transport networks experience heavy demand, often leading to challenges around congestion, health and safety, accessibility, and environmental asset degradation.

Over the past decade, the road sector has increasingly looked to emerging technologies as a means of increasing the efficiency and safety of existing networks in hopes of freeing up capacity and reducing harm to users. An increasing number of these emerging technologies have begun relying on various types of positioning technology for functionality.

15.2 Use of positioning technology

The road sector has witnessed a technological revolution over the past decade. The advent of ride-share applications, vehicle-to-vehicle communication, and vehicle-to-infrastructure applications have begun to shift the road sector towards an integrated, intelligent transport system.

The use of positioning across these technologies varies; however, there is an overarching requirement for positioning reliability, integrity, and increasingly interoperability between different platforms. This contrasts with what has historically been expected from positioning technologies, which have primarily been limited to point-to-point journey navigation using standalone GNSS.

Research to date[292] has shown that standalone GNSS lacks the positioning accuracy required for automated vehicles and intelligent transport systems (ITS), whilst limiting future road user charging (RUC) options for central government and local authorities. For example, whilst standalone GNSS may be able to accurately identify which road a vehicle is on, it cannot accurately identify the exact lane or its position within a lane. This level of accuracy becomes critical when looking at applications such as C-ITS, which encapsulate vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) safety applications.

V2V allows vehicles to essentially see further than a direct line of sight and enhance the level of predictability. Imagine a vehicle in front of you communicating with your vehicle about the intent of a lane change before it even makes a change, or relaying information to all nearby vehicles about a flat tyre at the moment it happens.[293] V2I allows vehicles to communicate with the road environment to capture infrastructure data and provide travellers with real-time advisories about such things as road conditions, traffic congestion, accidents, construction zones, and parking availability[294].

Both applications are vital to connected and automated vehicles (CAVs), and broader ITS which could ultimately help deliver initiatives such as smart travel demand management and road pricing.

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[292] Austroads (2013) Vehicle positioning for C-ITS in Australia (Background document). Retrieved from: https://austroads.com.au/publications/connected-and-automated-vehicles/ap-r431-13

[293] Ahmed, S. (2018) Get to know connected vehicle technology: V2V, V2X, V2I. Retrieved from: https://www.geotab.com/blog/connected-vehicle-technology/

[294] Rouse, M (2017) Vehicle to infrastructure (V2I or v2i). Retrieved from: https://whatis.techtarget.com/definition/vehicle-to-infrastructure-V2I-or-V2X

15.3 Demonstrator Project descriptions

Four Demonstrator Projects were commissioned to investigate the potential of the SBAS signals to the road sector.

Collectively these Demonstrator Projects helped gauge the performance of the SBAS signals throughout the transport network. Testing of the SBAS signals occurred within the urban network which is subject to urban canyons[295] and the rural network which includes remote rural areas. This level of coverage provides a good background to the economic work because it shows the performance of the SBAS signals across a wide range of conditions in Australia and New Zealand, thereby supporting the scaling benefits for the wider sector.

The participating organisations, the focus of their trials, and the signals tested are detailed briefly in Table RO1.

Table RO1 – Road Demonstrator Project descriptions

Demonstrator projects	Description	Signals tested
Curtin University/ Transport for NSW	Exploring the benefits of the SBAS signals for C-ITS safety applications and efficiency applications, via freight priority lanes, within New South Wales.	L1, DFMC, PPP
VicRoads	Exploring the benefits of the SBAS signals for CAV navigation within Victoria.	L1, DFMC, PPP
Ministry of Transport, New Zealand	Exploring the applicability of the SBAS signals in helping support policy decisions for road pricing and electronic road user charge management.	L1, DFMC, PPP
HERE Technologies	Exploring the benefits of the SBAS signals for road network mapping and 3D spatial modelling for CAV navigation.	L1, DFMC, PPP

15.4 Anticipated benefits

In attempting to understand the economic benefits accruing to the road sector from implementation of the SBAS signals, a benefits mapping exercise was undertaken with the various Demonstrator Projects (and some other stakeholders in the sector) to identify how their performance flowed through to operational benefits. This led to the identification of nine potential operational benefits:

Improved journey times via enablement of CAVs

Traffic congestion occurs when travel demand exceeds the existing road system capacity. CAVs are unlikely to alter physical capacity of existing infrastructure but stand to directly affect traffic congestion by enabling greater vehicle throughput on existing roads.

While it is acknowledged that the SBAS signals have the potential to play a key role in the enablement of CAVs, specifically around absolute positioning, the specific role of the SBAS signals and the degree to which CAVs may be reliant on it remains unclear. This is due to a host of factors, including but not limited to ambiguity surrounding regulation and preferred CAV technologies within the market.

Discussion around the congestion benefits associated with CAV adoption is somewhat speculative; however, overall, research indicates that the broad adoption of CAVs could lead to significant reduction in congestion and an even greater reduction in the costs associated with it[296,297].

Decreased collision risk via enhanced C-ITS safety applications

In 2017, there were 1,225[298] and 378[299] deaths on Australian and New Zealand roads respectively. When coupled with other road traumas including

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[295] Urban canyons are highly obstructed environments within cities, such as areas with tall buildings, which block or distort GNSS signals.

[296] Clements, L. and Kockelman, K (2017) Economic effects of automated vehicles. Retrieved from: https://www.caee.utexas.edu/prof/kockelman/public_html/TRB17EconomicEffectsofAVs.pdf

[297] While potentially stimulating additional Vehicle Kilometres Travelled (VKT).

[298] Department of Infrastructure, Regional Development and Cities (2017) Road deaths Australia: December 2017. Retrieved from: https://bitre.gov.au/publications/ongoing/rda/files/RDA_Dec_2017.pdf

[299] Ministry of Transport (2018) Annual number of deaths historical information. Retrieved from: https://www.transport.govt.nz/mot-resources/road-safety-resources/road-deaths/annual-number-of-road-deaths-historical-information/

injuries this equated to costs of approximately $30b[300] and $4.17b[301] to the Australian and New Zealand economies. This cost is incurred through loss of life, reduced quality of life, loss of output due to temporary incapacitation, medical costs, legal costs, and property damage costs.

This has spurred both the Australian and New Zealand Governments to put strategies in place to help minimise and aim to eliminate crashes on road networks. Road authorities are currently examining the deployment of C-ITS, which stands to benefit from the SBAS signals.

Improved journey times via C-ITS signal priority applications

Heavy vehicles, which include buses, trucks, and other movers of freight, have a disproportionate impact on network efficiency, due to the additional time associated with acceleration and deceleration. For example, congestion costs Sydney $5b per year, with approximately 50 percent of the economic cost derived from freight movements, even though they make up a small percentage of total vehicles on the road[302].

Whilst there is an array of C-ITS applications with the potential to have a positive impact on network efficiency, signal priority applications, which allow drivers of priority vehicles (for example emergency vehicles, public transport, and other heavy vehicles) to be given priority at signalised junctions, stand to provide the most material benefits to the wider network. This is because it helps minimise heavy vehicle deceleration and acceleration as well as the subsequent ripple effects throughout the network. It is anticipated that the SBAS signals will also improve the effectiveness of signal priority applications.

Reduction in RUC administrative costs

Currently most RUC licenses across Australia and New Zealand are administered manually; however, an increasing proportion are transferring to electronic RUC (eRUC) systems which reduce the administrative burden and associated costs on the government. Deployment of the SBAS signals are anticipated to reduce the cost of eRUC systems, which in turn is anticipated to accelerate the uptake of eRUC, and help government realise benefits sooner.

Enablement of distance-based and real-time tolling

In addition to enablement of administrative savings, the increased uptake of eRUC is anticipated to further support the conditions needed for a fleet-wide revenue collection system.

Additionally, it is anticipated that the ability to accurately locate the absolute position of a vehicle within a lane using the SBAS signals will broaden the range of demand management options available to government, including real-time road pricing, should it ever be considered in the future. This has potential to result in reduced delays, increased travel time reliability, reduced emissions, and improved economic productivity.

Enhanced mobility and accessibility for under-served populations

The positioning accuracy offered by the SBAS signals has potential to serve as one of many enablers for the eventual roll out of CAVs. Vehicle automation can increase the mobility of currently under-served populations, for example the visually impaired, elderly, and non-drivers, by increasing travel options available to them.

Lowering of market barriers for safety applications

Deployment of the SBAS signals is anticipated to help drive the introduction of safety applications and related technologies in the Australian and New Zealand vehicle market. In simple terms, there is a risk that not having the SBAS signals will preclude certain vehicles being imported into Australia and New Zealand that have C-ITS safety applications as standard, or are manufactured in overseas markets like Europe, UK, Japan, and US (which all have access to L1 and PPP)[303].

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[300] Australian Automobile Association (2017) Cost of road trauma in Australia. Retrieved from: https://www.aaa.asn.au/wp-content/uploads/2018/03/AAA-ECON_Cost-of-road-trauma-summary-report_Sep-2017.pdf

[301] Ministry of Transport (2018) Social cost of road crashes and injuries. Retrieved from: http://www.transport.govt.nz/research/roadcrashstatistics/thesocialcostofroadcrashesandinjuries/

[302] Information provided by a Demonstrator Project

[303] In addition to commercial PPP solutions, at the time of writing it is understood that Europe, China, and Japan are also considering the provision of open access PPP through their own GNSS.

Mapping efficiencies

The SBAS signals are anticipated to reduce the post-processing times for vehicle-captured mapping data, which can reduce production times and associated operating expenditure for businesses that produce road maps. Post-processing improvements in the context of this benefit refer to the reduced need for cross-referencing of collected spatial data against ground-based reference stations, which mapping providers must pay to use. By reducing the reliance on cross-referencing, map providers can potentially also avoid associated subscription costs.

Enabling self-healing maps for CAVs

Sensor integration is a term used to describe a method of positioning where information from a variety of sensors, such as LiDAR, is stitched together to optimise pre-rendered 3D maps pre-loaded in vehicles, to determine absolute positioning[304]. SBAS has the potential to enable live or self-healing 3D maps, which update based on real-time changes in the urban environment, thereby unlocking the use of sensor integration as a positioning method in CAVs.

Anticipated benefits have been classified into benefit categories, as shown in Table RO2[305].

Table RO2 – Road sector benefit categorisation

Benefit	Benefit category	Quantitative?
Improved journey times via enablement of CAVs	Operating expenditure savings	Yes
Decreased collision risk via enhanced C-ITS safety applications	Health and safety	Yes
Improved journey times via C-ITS signal priority applications	Operating expenditure savings	Yes
Reduction in RUC administrative costs	Operating expenditure savings	No
Enablement of distance-based and real-time tolling	Operating expenditure savings	No
Enhanced mobility and accessibility for under-served populations	Operating expenditure savings	No
Lowering of market barriers for safety applications	Health and safety	No
Mapping efficiencies	Operating expenditure savings	No
Enabling self-healing maps for CAVs	Operating expenditure savings	No

15.5 Positioning needs and current methods

Unlike the other sectors presented as part of the Demonstrator Projects, many of the anticipated benefits within the road sector (all apart from RUC-related benefits) generally sit at the frontier of technology which has not yet become mainstream. The key implication for this analysis is that while there is recently formed consensus around the positioning needs of C-ITS, which for the purposes of this analysis has been extended to CAVs, the preferred method to meet those needs is yet to be determined.

Discussion around positioning needs within the road sector is typically categorised into three levels of positioning accuracy:

- Road level (which road and direction a vehicle is travelling on)
- Lane level (which lane a vehicle is in)
- Where in lane level (where a vehicle is located within a given lane).

The positioning requirements for each of the three categories are outlined in Table RO3[306]. These form the basis for the positioning requirements of CAVs and C-ITS applications, required for the economic benefits described in this assessment, to accrue. It is important to note that positioning requirements can differ between applications[307].

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[304] Hexagon and NovAtel (2018) High-precision GPS for autonomous vehicles. Retrieved from: https://www.novatel.com/industries/autonomous-vehicles/#technology

[305] Colour coding in Table RO2 has been used to more clearly highlight the relevant benefit categories

[306] Kealy, A. (2009) Assessment of positioning accuracy for co-operative intelligent transport systems. Retrieved from: http://users.monash.edu.au/~mpetn/files/talks/Kealy.pdf

[307] Pauls Consultancy BV (2015) D2.1 Use cases and application requirements. High precision positioning for co-operative-ITS.

Table RO3 – CAV and C-ITS positioning requirements

Level	Accuracy requirement (horizontal)
	95% confidence level (m)
Road level	<5.0
Lane level	<1.5
Where in lane level	<1.0

There remains no consensus about the criticality of the SBAS signals in enabling the uptake of CAVs and C-ITS. However, discussion with the sector suggests that access to the SBAS signals remains beneficial as it is anticipated to improve Australia and New Zealand's ability to better receive new international technologies and provide an added layer of redundancy to existing positioning systems.

15.5.1 Improved journey times via enablement of CAVs

The future of how we travel in cities could change dramatically with the introduction of CAV technologies. CAVs represent the combination of two technologies: connected vehicles (CV) and automated vehicles (AV). Connected vehicles use communication technologies, such as V2V and V2I, to exchange information with other cars on the road.

Whilst they remain connected, this does not necessarily mean they are automated and can operate independent of a human driver. AVs represent vehicles which operate with varying levels of self-driving automation. Table R04 shows there are six levels of automation[308].

Table RO4 – AV automation levels

Automation	Description
Level 0	Human driver performs all driving tasks
Level 1	Either lateral or longitudinal driving assistance to human driver
Level 2	Lateral and longitudinal driving assistance to human driver
Level 3	Full automation of certain driving tasks with human driver ready to intervene if required
Level 4	Full automation of certain driving tasks without any expectation that a user will respond to request to intervene
Level 5	Full automation of all driving tasks without any expectation that a user will respond to request to intervene

To that end, CAVs represent automated vehicles which talk to each other to improve:

- Car-following behaviour
- Lane changing and gap acceptance behaviour
- Profiles of acceleration and deceleration
- Connectivity to represent the better provision of information[309].

Given the emerging nature of this technology, it is important to understand that positioning technology is not the sole enabler of CAVs, but rather one of 11 high-level components required (as shown in Figure R04[310]). The emerging nature of CAV technology means there are numerous schools of thought around how CAVs are bundled. For the purposes of this analysis 11 components have been assumed in discussion with various Demonstrator Projects[311].

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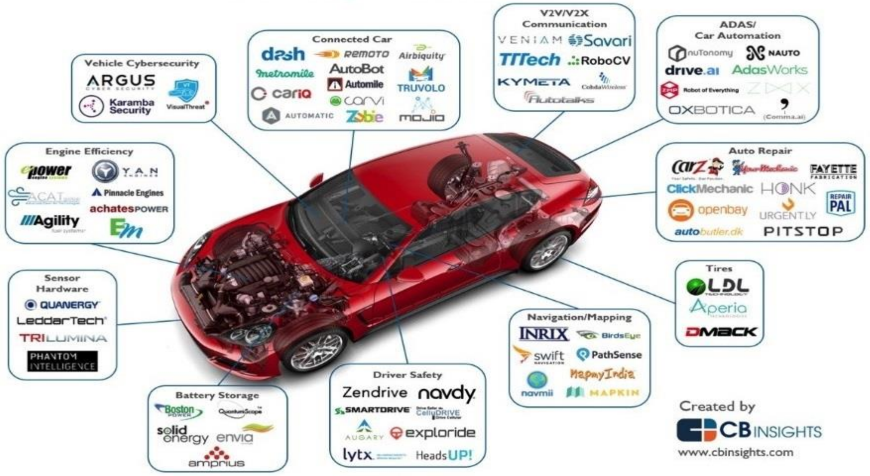
[308] SAE International. (2018) Surface vehicle recommended practice: Taxonomy and definitions of terms related to driving automation systems for on-road motor vehicles. Retrieved from: https://www.sae.org/standards/content/j3016_201401/

[309] Department for Transport (2016) Research on the impacts of connected and autonomous vehicles (CAVs) on Traffic Flow. Retrieved from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf

[310] Curry, D. (2016) Who are the start-ups upgrading the auto industry? Retrieved through: https://readwrite.com/2016/08/09/startups-attempting-upgrade-auto-industry-tl4/

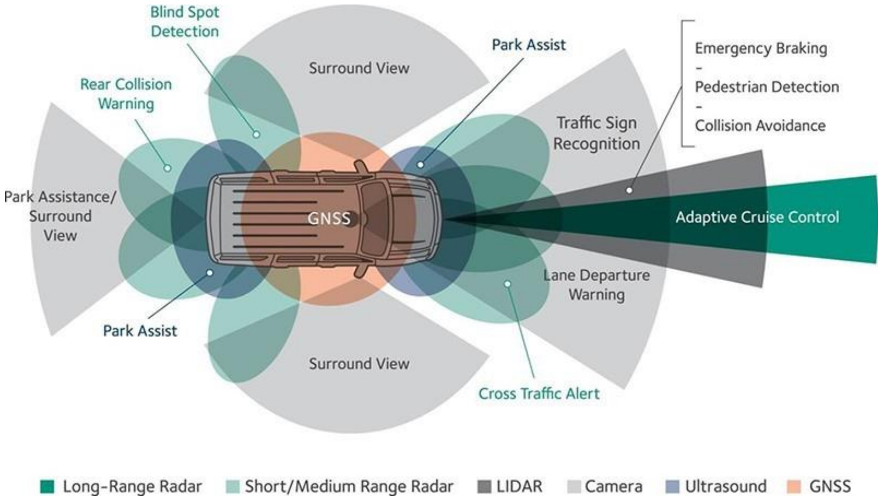
[311] It is noted that there was conjecture about the necessity for 'auto-repairs' to be considered a core part of CAVs. However, this component is a design feature for those start-ups cited that are developing this technology and so has been included in the modelling.

Figure RO4 – CAV components



As shown in Figure RO5[312], within the positioning component a CAV relies on a combination of standalone GNSS positioning and localised sensors to navigate around a transport network.

Figure RO5 – Positioning technologies used for CAVs



GNSS technology is primarily used for absolute positioning, which helps determine the exact position of a CAV in the world so that it may navigate from Point A to Point B autonomously. The need to make this journey along specific road lanes and speed limits suggests lane level accuracy is required. Given the inherent inaccuracies of standalone GNSS, it is proposed that the SBAS signals have a significant role to play in providing reliable absolute positioning to CAVs.

On board, localised sensors assist a CAV to navigate the immediate surrounding environment, which often contains moving objects such as pedestrians and other vehicles. Sensors such as LiDAR, cameras, long-range and short-range radars, and ultrasound help provide the CAV with a detailed view of the surrounding environment. This in turn assists in detecting surrounding pedestrians, deploying emergency braking where necessary, and engaging collision avoidance systems when driving amongst other cars in a live environment. While SBAS signals can potentially provide centimetre level positioning with the aid of additional sensors, they cannot do so on their own. To that end, given the centimetre accuracies required for localised positioning, the SBAS signals are not anticipated to offer any benefits.

Research[312] suggests that there are four options available to manufacturers with regards to absolute positioning: RTK, the SBAS signals, standalone GNSS aided by additional sensors, and high-definition maps with data from localised sensors (sensor integration). The last option, sensor integration, refers to the stitching of pre-rendered 3D maps with data from localised sensors to determine the absolute position of a CAV. Currently, there remains no consensus on the preferred positioning technology to determine absolute positioning for CAVs. Therefore, it has been assumed that the SBAS signals serve as one of four base case futures for CAVs; with the other three being RTK, standalone GNSS aided by sensors, and sensor integration.

15.5.2 Enhanced C-ITS safety and signal priority applications

The C-ITS safety applications and C-ITS signal priority applications benefits have been combined for this section.

Based on discussions with the road sector, ITS is seen as a significant tool in current and future efforts to reduce fatalities and serious injuries on the transport network (noting there remain other health and safety technologies which may benefit from the SBAS signals, but not provide material benefits). ITS is an umbrella term for many electronic, information processing,

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[312] Hexagon and NovAtel (2018) High-Precision GPS for Autonomous Vehicles. Retrieved from: https://www.novatel.com/industries/autonomous-vehicles/#technology

communication, and control technologies that may be combined and applied to the transport domain. Intuitively, any ITS must show at least some form of information processing, computing, or vehicular/road network control to be considered intelligent.

ITS serves many functions. ITS may interact with a single user or vehicle or influence an entire road network[313]. ITS can be used to improve traffic safety, traffic flow and capacity, vehicle efficiency, reduce vehicle emissions, and resource consumption[315].

ITS can be categorised in several ways; however, one of the broadest and most common classifications revolves around the positioning of the system, i.e. whether the system is in-vehicle, infrastructure-based, or co-operative:

In-vehicle systems

These refer to technologies based within the vehicle. These typically involve sensors, information processors, and on-board units or displays that: provide additional information to the user, automate or intervene with some part of the driving task, or provide warnings to the user about potential hazards.

Infrastructure-based systems

These may serve one of two general functions: to provide drivers with additional information via roadside messages, or to better manage and control traffic flow. In both instances, various types of sensors are used to gather information from the road-side infrastructure to influence traffic behaviour.

Co-operative systems

Co-operative systems involve communication between vehicles and relevant infrastructure or involve communication between vehicles. This communication may be one way, (where the vehicle receives information from the infrastructure but does not transmit information in return) or two-way (where the vehicle both sends and receives information from another vehicle or infrastructure-based system).

In-vehicle and infrastructure-based ITS can be considered traditional ITS, which currently exists in the market to varying degrees. The former has been shown to reduce road-related fatalities and serious injuries via V2V applications such as forward collision warnings, intersection collision warnings, and blind spot/lane change warnings. The latter has been proven to have a positive impact on network efficiency via V2I applications such as signal priority, smart routing, and smart parking applications[314].

C-ITS augments traditional ITS by facilitating real-time communication between vehicles and infrastructure over larger distances typically via a cloud-based system, instead of relying on the local sensors used by traditional ITS. V2V and V2I can be considered C-ITS applications in this regard. For example, an ITS utilises local radar sensors for forward collision avoidance systems, whereas C-ITS complements radar sensors by enabling vehicles to talk to each other and determine their position relative to each other at all times.

For ITS, a forward collision avoidance system would not detect an obstacle until it was within a certain radius of a stationary vehicle, and for C-ITS, the vehicle would be notified of the stationary vehicle well in advance of even seeing it. To that end, ITS stands to gain minor safety benefits from the SBAS signals, given its reliance on local sensors; however, it may find benefits in relation to hazard or trip advisory applications that may impact on network efficiency. Given the requirement of C-ITS to communicate with other vehicles and infrastructure, absolute positioning, which then informs relative positioning, is critical.

Similar to CAV technology, positioning forms one of six components in C-ITS technology, the others being: sensors, software, wireless networks, automated controls, and critical component testing and maintenance[315]. Research suggests there are five methods available to the market to fulfil the positioning component of C-ITS. These are detailed in Table RO5[316].

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[313] Bayley, M. et al (2007) Review of crash effectiveness of intelligent transport systems. Retrieved from: http://www.trace-project.org/publication/archives/trace-wp4-wp6-d4-1-1-d6-2.pdf

[314] European Commission (2016) Study on the deployment of C-ITS in Europe: final report. Retrieved from: https://ec.europa.eu/transport/sites/transport/files/2016-c-its-deployment-study-final-report.pdf

[315] Litman, T (2019) Autonomous vehicle implementation predictions: implications for transport planning. Retrieved from: https://www.vtpi.org/avip.pdf

[316] Kealy, A. (2009) Assessment of Positioning Accuracy for Co-operative Intelligent Transport Systems. Retrieved from: http://users.monash.edu.au/~mpetn/files/talks/Kealy.pdf

Table RO5 – Positioning techniques for C-ITS

Technique option	Status		Accuracy range	Cost
	Current	Future		
1a	Standalone GPS	Standalone multiple GNSS	10-20m	Low
1b	Standalone GNSS	Standalone multiple GNSS positioning	1-10m	Low
2	Current WAAS Commercial Wide Area DGPS	Future SBAS design for multiple GNSS	0.1-1m	Low
3	Smoothed DGPS (differential GPS)	Smoothed DGNSS		Medium
4	PPP	Combined PPP and RTK	0.01-0.1m	Medium to high
5	RTK			

The accuracy requirements for individual emerging C-ITS applications are yet to be specified, therefore the percentage of applications which require certain levels of positioning accuracy could not be identified. However, what researchers[317] have been able to establish are the positioning requirements of the general types of C-ITS applications based on the three categories in Table RO3.

The higher the positioning resolution, the greater the level of accuracy achieved and therefore the more effective C-ITS is in minimising health and safety risks and managing priority lanes. As an example, road-level accuracy may notify a driver of an upcoming road hazard around the corner, lane-level accuracy may assist with driver fatigue detection as a result of swerving and deploy alerts and where-in-lane level accuracy may improve collision detection systems via enhanced longitudinal and lateral positioning accuracy.

The importance placed on absolute positioning relates not only to the ability to track individual vehicles, but to accurately understand exactly where two vehicles are on a map relative to each other, or where a vehicle is relative to co-operative infrastructure, to understand distance. This is the fundamental idea behind C-ITS. Having a clear understanding of *relative* positioning enables vehicles to proactively deploy C-ITS safety applications. It also enables vehicles to communicate with the network to identify optimal navigation paths and parking spaces to improve efficiency.

Traffic signal priority applications, which are considered the most beneficial V2I application to reduce heavy vehicle impacts on the transport network, allow drivers of priority vehicles (for example emergency vehicles, public transport, and freight trucks, but almost always heavy vehicles) to be given priority at signalised junctions.

This is done by installing a receiver and transmitter on both the traffic signal and the priority vehicle. When in proximity of a traffic signal, the priority vehicle transmits a priority request to the specific traffic signal to either speed up or prolong a green light to enable flow though[318].

Inaccurate positioning information of a priority vehicle relative to a traffic signal presents risks around the traffic signal remaining green for longer than it should, or switching to red faster than needed. Therefore, it is evident that lane-level positioning is required for signal priority applications, as signals cross traffic at the lane level.

Assuming Australia and New Zealand were interested in achieving the full range of C-ITS applications in a cost-effective manner, research suggests that the sub-metre positioning provided by the SBAS signals would be the optimal choice as shown in Table RO5. This is because they provide the optimal balance between accuracy and cost effectiveness. Cost effectiveness is a subjective term, but in this context, refers to equipment costs of less than $100 per unit in 2019 dollars.

For now, the technological path remains uncertain and ultimately dependent on market and regulatory preference. In lieu of certainty around the base case, the quantitative analysis noted below assumes that each of the five

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[317] Smith, E. et al (2016) Integrity monitoring methods for co-operative intelligent transport systems. Retrieved from: http://www.ignss2016.unsw.edu.au/sites/ignss2016/files/u80/Papers/non-reviewed/IGNSS2016_paper_30.pdf

[318] Bayley, M. et al (2007) Review of crash effectiveness of Intelligent Transport Systems. Retrieved from: http://www.trace-project.org/publication/archives/trace-wp4-wp6-d4-1-1-d6-2.pdf

options noted above will have equal market share of any C-ITS benefits attributed to the positioning component of C-ITS.

15.5.3 Reduction in RUC administrative costs

Existing eRUC systems rely on a range of information sources to determine the time, location and distance travelled of relevant vehicles. Standalone GNSS is one such source of information currently employed.

Discussion with the sector states that the minimum requirement for the SBAS signals to be considered a viable alternative to standalone GNSS would be road-level although lane level positioning would enable a range of ancillary policy tools to be explored (such as lane tolling).

15.5.4 Enablement of distance-based and real-time tolling

Different road pricing methods have different positioning requirements. The purpose of this study is not to suggest a specific method, but rather highlight the variety of options made available to government via wide-coverage, free, and highly accurate positioning information provided by SBAS signals. To that end, whilst there is no specific positioning requirement for this benefit, it is acknowledged that lane-level accuracy is a minimum requirement, to enable a change in the variety of road pricing options made available to government.

15.5.5 Enhanced mobility and accessibility for under-served populations

Please refer to section 15.5.1, given the reliance of this benefit on enablement of CAVs.

15.5.6 Lowering of market barriers for safety applications

Please refer to section 15.5.2, given the reliance of this benefit on enablement of C-ITS.

15.5.7 Mapping efficiencies and enabling of self-healing maps for CAVs

The mapping process for vehicles, and eventually CAVs, relies on a combination of absolute and relative positioning. Similar to CAV navigation, absolute positioning is undertaken using a combination of standalone GNSS and/or sensor integration, with relative positioning undertaken using a variety of sensors. Absolute positioning, in terms of mapping, is quite important, as it helps anchor objects measured by the system close to their true geographical location. Improved absolute positioning helps reduce the amount of post-processing required to produce accurate maps from collected data and will help pave the way for self-healing maps in the future.

Given its similarity to CAV navigation, it is proposed that lane-level positioning remains sufficient for gains in mapping efficiency, whilst decimetre positioning accuracy is required for self-healing maps, due to its need to rapidly update environments in a granular format for real-time CAV navigation.

15.6 Sector benefits

Given the immaturity of the technologies required to unlock the benefits of the SBAS signals within the road sector, quantification of benefits has proved to be more challenging compared to other sectors. This is primarily due to uncertainty around the future uptake scenarios, attribution issues at a signal level and inconsistent views around the effectiveness of CAVs and C-ITS. Nevertheless, certain assumptions as part of the quantification exercise have been made, which are elaborated in 15.8 of this Chapter.

15.6.1 Signal attribution

Table RO6 details how the benefits accrue to each of the SBAS signals based on signal performance and the positioning needs of each of the anticipated benefits. PPP is anticipated to perform the strongest with regards to C-ITS and CAV benefits. This is because PPP is anticipated to provide the lane-level accuracy required by C-ITS and CAV, in addition to the incremental benefits derived from providing decimetre-level accuracy. The limitation of L1 and DFMC to sub-metre accuracy only is reflected in the minor discount afforded to their attribution rate relative to PPP.

Discussion with the sector suggests a degree of price sensitivity with regards to potential RUC options enabled by the SBAS signals. Moreover, convergence times might also present issues regarding tunnels and urban canyons. Given the minimal change in receivers required for L1 and DFMC, in particular, both receivers are therefore anticipated to accrue full benefits relating to RUC and demand management.

Indicative test results have been provided by FrontierSI as representative results of the testing carried out by the SBAS Demonstrator Project in this sector. Values are presented at a 95 percent confidence interval. Where deviations exist, DFMC SBAS results are expected to be similar to SBAS L1 in an operational system.

The testing was carried out in lightly to significantly obstructed environments with mid-range equipment. All known road benefits relate to horizontal positioning needs; however, vertical positioning can be useful for CAVs and C-ITS as well as an additional check, especially if roads are on different levels.

Table RO6 – Road sector signal attribution

Signal	Road sector test results	
	Expected horizontal performance (m)	Expected vertical performance (m)
L1	1.1	3.0
DFMC	2.0	3.1
PPP	0.6	1.0

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Quantitative benefits					
Improved journey times via enablement of CAVs	Lane level	90%	90%	100%	PPP offers an incremental accuracy benefit over L1 and DFMC
Decreased collision risk via enhanced C-ITS safety applications	Sub-metre	90%	90%	100%	PPP offers an incremental accuracy benefit over L1 and DFMC
Improved journey times via C-ITS signal priority applications	Lane level	90%	90%	100%	PPP offers an incremental accuracy benefit over L1 and DFMC
Qualitative benefits					
Reduction in RUC administrative costs	Lane level	✓	✓	-	PPP receiver cost barrier for inclusion
Enablement of distance-based and real-time tolling	Lane level	✓	✓	-	PPP receiver cost barrier for inclusion
Enhanced mobility and accessibility for under-served populations	Lane level	✓	✓	✓	PPP offers an incremental accuracy benefit over L1 and DFMC
Lowering of market barriers for safety applications	Sub-metre	✓	✓	✓	PPP offers an incremental accuracy benefit over L1 and DFMC
Mapping efficiencies	Lane level	✓	✓	✓	PPP offers an incremental accuracy benefit over L1 and DFMC
Enabling self-healing maps for CAVs	Decimetre	-	-	✓	Fine grain view of 3D world required for sensor integration

15.6.2 Uptake rate

The uptake, and therefore effectiveness, of C-ITS benefits is anticipated to be exponential from one percent to 53 percent[319] over a 30-year period, as

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[319] 53 percent represents the upper bound of C-ITS effectiveness at 2050, based on estimate around automation, and market uptake.
Automation: Department for Transport (2016) Research on the impacts of connected and autonomous vehicles (CAVs) on Traffic Flow. Retrieved from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf
Market uptake: European Commission (2016) Study on the deployment of C-ITS in Europe: final report. Retrieved from: https://ec.europa.eu/transport/sites/transport/files/2016-c-its-deployment-study-final-report.pdf

existing vehicles are retrofitted with aftermarket systems, newer more well-equipped vehicles enter the fleet and automation increases.

In terms of CAVs, full automation is not anticipated to enter the market until 2030, after which it is expected to follow a linear uptake curve towards full adoption around 2060[320], reflecting a combination of early adopters and lagging regulation.

An S-curve uptake curve has been deployed for all RUC-related benefits in the road sector over the 30-year assessment period. This reflects discussion with the sector which suggests slow initial uptake reflected by early adopters, followed by exponential uptake as most of the market follows suit, and a steady plateau in the long-run. It is acknowledged that this uptake curve is subject to change depending on future regulatory and policy change.

15.6.3 Quantitative benefits

15.6.3.1 Improved journey times via enablement of CAVs

Travel time savings attributable to the SBAS signals across the entire transport network as a result of enablement of CAVs is anticipated to result in PV$760m in improved productivity within (and stemming from) the road sector across Australia and New Zealand over a 30-year period.

In calculating this benefit, average journey times across Australia and New Zealand were first multiplied by the total number of trips over a 30-year period and then by the anticipated CAV travel time saving to determine the anticipated time saved due to implementation of CAVs. Importantly, it is assumed that not all time saved because of CAVs will be productive, therefore only 70 percent of all travel time savings have been assumed to be productive[321].

Travel time savings resulting from CAVs are taken from a study undertaken by the UK Department of Transport[322] on the impact of CAVs on transport network efficiency. As part of this study, the Department of Transport undertook a microsimulation exercise to understand the impact of CAVs on urban and strategic network journey times, which were found to improve as CAV penetration increased.

It is anticipated that CAV penetration will go from 25 to 75 percent between 2030 and 2050, resulting in a corresponding travel time saving of 6 to 10 percent over the same period. It is acknowledged that there is potential for travel time savings below 25 percent CAV market penetration; however, given the lack of critical mass, it is considered marginal and difficult to quantify.

Total productive travel time savings were then adjusted for positioning technology and the SBAS signals attribution, before being multiplied by the value of time and applying a discount for present values to arrive at a total economic benefit as shown in Table RO7.

Table RO7 – CAV journey time saving breakdown (30-year calculation)

Factor	Value	Notes
Total vehicle kilometres travelled (VKT)	8,693b km	AUS and NZ data, cumulative km travelled over 30-year period
Average trip VKT	16km to 30km	Based on AUS and NZ data, with trip lengths increasing over 30 years
Total trip count	427b	Total VKT divided by average trip VKT on per annum basis
Anticipated CAV time saving	4.5b hours	Trip count multiplied by average journey time and CAV time saving (6% up to 10% from 2030 onwards)
Anticipated productive time saving	3.15b hours	Assuming 70% of time saved is productive
Time saved attributable to positioning	284m hours	Assuming 11 core components of a CAV system
Time saved attributable to the SBAS signals	70m hours	Assuming four positioning options
Value of time saved	$3b	Based on $42per hour value of time[323]

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[320] Kealy, A. (2009) Assessment of positioning accuracy for co-operative intelligent transport systems. Retrieved from: http://users.monash.edu.au/~mpetn/files/talks/Kealy.pdf. It is noted that this date is beyond the timeframe of this sectoral analysis, but has been used as an input into uptake curve calculations.

[321] Based on in-house EY SME economics expertise.

[322] Department for Transport (2016) Research on the impacts of connected and autonomous vehicles (CAVs) on traffic flow. Retrieved from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf

[323] Australian transport and planning (2016) Travel time. Retrieved from: https://atap.gov.au/parameter-values/road-transport/3-travel-time.aspx

Factor	Value	Notes
Present value	$760m	Discounted at 6.5%

Note: Totals may not sum due to rounding

15.6.3.2 Decreased collision risk via enhanced C-ITS safety applications

Over a 30-year assessment period, it is anticipated that a total of 45 fatalities and 2,800 serious injuries will be avoided via implementation of C-ITS and attributable to the SBAS signals, resulting in an economic saving of PV$277m across Australia and New Zealand.

One of the first considerations of C-ITS is acknowledgement that it cannot affect the outcomes of every type of accident. Instead, research suggests that the following accident types may be positively affected by C-ITS safety applications[324]:

- Vehicles approaching from adjacent directions
- Vehicles approaching from opposing directions
- Vehicles approaching from same directions
- U-turns
- Overtaking
- Off path on straight
- Off path on curve

Cumulatively, these accident types represent approximately 38 percent of total fatalities and 49 percent of total serious injuries within the sector[325].
It is important to note, however, that the term affected in this context simply implies that the outcome of these accidents can be influenced by C-ITS, which does not require 100 percent of these accidents to be avoided by the system.

The ability to avoid accidents is determined by the effectiveness of C-ITS, which is influenced by the following three factors:

- The success rate of C-ITS applications in avoiding accidents
- The level of automation present within the subject vehicle fleet
- The penetration of C-ITS applications within a vehicle fleet.

Austroads[326] research into the use of C-ITS for collision avoidance systems states that the success rate of C-ITS applications depends on two factors:

- The probability of a driver responding to a C-ITS warning and of the drivers who respond:
- The probability that their subsequent response is effective at avoiding a collision.

The study goes further to suggest that there is an 80 to 90 percent probability of drivers responding to warnings and of those drivers, 65 to 80 percent successfully avoiding a collision – placing the success rate of C-ITS at avoiding collisions between 52 and 72 percent.

Importantly, probability of success across each of the two factors increases as automation increases. Therefore, an automation overlay has been applied to the C-ITS success rate over time, to reflect steady progression from Level 0 automation to Level 5 automation across the vehicle fleet. It is anticipated that 60 percent of the fleet will achieve Level 3–4 automation by 2050[326].

Lastly, the success rate of C-ITS avoiding accidents is irrelevant if there is no uptake, therefore the overall effectiveness of C-ITS is modified to account for an uptake curve. Research[327] suggests 100 percent penetration of C-ITS across new executive and medium sized vehicles by 2035 and across new small vehicles and used vehicles by 2045.

Taking this into account, as shown in Tables R06 and R07 it is anticipated that over 30-year period a little more than 1,300 fatalities and 82,000 serious

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[324] Austroads (2011) Evaluation of the potential safety benefits of collision avoidance technologies through vehicle to vehicle dedicated short range communications (DSRC) in Australia. Retrieved from: https://austroads.com.au/publications/road-safety/ap-r375-11

[325] TfNSW and VicRoads fatality and serious injury 2016 data used as proxies.

[326] Department for Transport (2016) Research on the impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow. Retrieved from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf

[327] European Commission (2016) Study on the Deployment of C-ITS in Europe: Final Report. Retrieved from: https://ec.europa.eu/transport/sites/transport/files/2016-c-its-deployment-study-final-report.pdf and Bayley, M. et al (2007) Review of crash effectiveness of Intelligent Transport Systems. Retrieved from: http://www.trace-project.org/publication/archives/trace-wp4-wp6-d4-1-1-d6-2.pdf

injuries will be avoided within the road sector across Australia and New Zealand due to C-ITS. Of this number, 3.4 percent of avoided fatalities and serious injuries can be attributed to the SBAS signals. This attribution figure reflects the notion that deploying SBAS signals tomorrow does not unlock all benefits. It acknowledges that positioning technology forms one of six components of C-ITS and that the SBAS signals form one of five alternative options assumed to fulfil the positioning component requirement of C-ITS.

The intention of this attribution process is not to understate the criticality of the SBAS signals, and the broader positioning component of C-ITS, but rather acknowledge that there remain complementary components necessary to realise the full benefits.

The total number of fatalities and serious injuries avoided within the road sector across Australia and New Zealand due to C-ITS, and directly attributable to SBAS, were multiplied by a value-of-life figure, adjusted for uptake and discounted to present values to arrive at a final economic benefit as shown in Table RO8.

Table RO8 – Avoided fatalities and serious injuries from C-ITS (30-year calculation)

Factor	Value	Notes
Fatalities		
Total fatalities influenced by C-ITS	11,775	38% of total fatalities over 30 years deemed to be preventable by C-ITS
Total fatalities avoided by C-ITS	1,319	1% up to 53% C-ITS effectiveness rate assumed between 2020 and 2050
Fatalities avoided attributable to positioning	224	Assuming six core components of C-ITS
Fatalities avoided attributable to the SBAS signals	45	Assuming five positioning options
Total value of fatalities avoided	$155m	Based on statistical value-of-life figure of $3.45m
Present value	$42m	Discounted at 6.5%
Serious Injuries		
Total serious injuries influenced by C-ITS	560,000	49% of total serious injuries deemed to be preventable by C-ITs
Total serious injuries avoided by C-ITS	82,000	1% up to 53% C-ITS effectiveness anticipated between 2020 and 2050
Serious injuries avoided attributable to positioning	14,000	Assuming six core components of C-ITS
Serious injuries avoided attributable to the SBAS signals	2,800	Assuming five positioning options
Total value of serious injuries avoided	$963m	Based on cost of $344,000 per serious injury
Present value	$235m	Discounted at 6.5%

Note: Totals may not sum due to rounding

15.6.3.3 Improved journey times via C-ITS signal priority applications

The economic impact of travel time savings derived from C-ITS signal priority applications that is attributable to the SBAS signals is anticipated to be approximately PV$46m across the Australian and New Zealand road sector over a 30-year period.

In calculating this benefit, average time delays across the strategic and urban street networks were multiplied by the total amount of trips within the sector over a 30-year period and then multiplied by a 28 percent time saving derived from identified empirical research[328].

The total journey time savings within the road sector across Australia and New Zealand due to C-ITS priority signalling were then multiplied by a value of time

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[328] Department for Transport (2016) Research on the impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow. Retrieved from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf

metric[329], adjusted for uptake and discounted to present values to arrive at a final economic saving as outlined in Table R09.

Table R09 – C-ITS journey time saving (30-year calculation)

Factor	Value	Notes
Total annual trip count	427b trips	Based on official AUS and NZ vehicle trip data
Total delay time anticipated	5b hours	Average 0.01hr delay at intersections per trip[27]
Anticipated delay reduction from signal priority	165m hours	Anticipated 28% reduction in delays and taking into account 1% up to 53% effectiveness between 2020-50
Productive time saving	115m hours	Assuming 70% of time saved is productive
Time saved attributable to positioning	20m hours	Assuming six core components of C-ITS
Time saved attributable to the SBAS signals	4m hours	Assuming five positioning options
Value of time saved	$160m	Based on $42 per hour value of time[331]
Present value	$46m	Discounted at 6.5%

Note: Totals may not sum due to rounding

15.6.4 Qualitative benefits

15.6.4.1 Reduction in RUC administrative costs

Anyone using Australian or New Zealand roads must contribute towards its upkeep. In both countries, this contribution consists of a combination of RUC, fuel levies, licence fees, and registration fees, with Australia charging additional stamp duties[330]. Owners of heavy vehicles are required to pay higher registration and fuel levies/RUC relative to those owning light vehicles to ensure they pay their fair share of road spending.

A key difference between the two countries, however, is the requirement of heavy vehicles to pay annual charges in Australia, versus heavy and light vehicles that are powered by diesel being subject to distance-based charges (in 1,000km increments) in New Zealand[331]. Whilst enabling a more granular payment regime, distance-based charging in New Zealand also accrues greater administrative costs. To that end, while both countries could gain from the digitisation of manual RUC processes, discussion with the sector suggests that the New Zealand system stands to gain comparatively more, which is why the focus of this benefit remains on the New Zealand RUC system.

Existing manual RUC systems rely on odometers and hubometers to accurately record distances travelled. The introduction of eRUC systems has enabled users to record and report data from a range of sources (including standalone GNSS, inertial devices – including gyroscopes – and odometers), leading to administrative savings for both operators and the government. This is reflected in the government's transaction schedule for new RUC licenses (see Table RO10), with eRUC transactions approximately 25 to 50 percent cheaper than manual RUC transactions[332].

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[329] Aus: Australian Transport and Planning (2016) Travel time. Retrieved from: https://atap.gov.au/parameter-values/road-transport/3-travel-time.aspx
NZ: New Zealand Transport Agency (2016) Economic evaluation manual. Retrieved from: https://www.nzta.govt.nz/assets/resources/economic-evaluation-manual/economic-evaluation-manual/docs/eem-manual-2016.pdf

[330] Library of Congress (2015) National funding of road infrastructure: Australia. Retrieved from: https://www.loc.gov/law/help/infrastructure-funding/australia.php

[331] New Zealand Transport Agency (2018) Road user charges handbook. Retrieved from: https://www.nzta.govt.nz/assets/resources/road-user-charges/docs/road-user-charges-handbook.pdf

[332] Note that this assumes a cost recovery model.

Table RO10 – RUC transaction schedule

Transaction type	Cost
Online	$4.80
Counter sales	$7.80
Phone/fax	$8.63
eRUC	$2.10

The New Zealand Government has supported eRUC providers, through an enabling framework, to convert a greater proportion of the RUC fleet into eRUC users, highlighted by official data showing an increase of eRUC licences from 14 percent in January 2014 to 33 percent in January 2018 (as a proportion of total licences[333]).

Discussion with the sector suggests that deployment of the SBAS signals could help to reduce the equipment cost of existing eRUC systems by reducing the sources of truth required (due to the enhanced integrity in addition to lane-level accuracy afforded). If the lower cost barrier materialises, then this in turn could drive greater uptake of eRUC across the current fleet and help the government realise administrative savings sooner rather than later. However, the precise degree to which SBAS will contribute to an accelerated future state where eRUC has higher adoption rates than at present, is unclear.

The anticipated increase in uptake is subject to two key factors:

Demand elasticity

Specifically, the responsiveness of heavy and light vehicle fleet demand of eRUC relative to changes in prices.

Regulation

This can drive greater uptake through mandatory uptake requirements, or incentives, if a reduction in prices makes wholesale eRUC feasible.

A lack of data around RUC demand elasticities coupled with uncertainty around political appetite to implement regulation presents a further challenge to forecast accelerated eRUC uptake due to SBAS signals. To that end, four scenarios have been modelled instead to provide the reader with an overview of the potential scale and magnitude of growth (and administrative savings) that could be expected depending on uptake and regulation. The scenarios are as follows:

- **High-growth scenario**

  Strong uptake over the base case.
- **Medium-growth scenario**

  Medium uptake over the base case.
- **Low-growth scenario**

  Minimal increase in uptake over the base case.
- **Mandatory uptake scenario**

  Mandatory compliance regulation introduced at year 2030.

The PV benefits for each scenario are outlined in Table RO11. Figure RO6 shows how each scenario trended over the 30-year assessment period.

Table RO11 – Accelerated eRUC scenario benefits (30-year calculation)

Scenario	Value
High growth	$15m
Medium growth	$7m
Low growth	$0.3m
Mandatory uptake	$32m

Based on the modelling, maximum uptake by 2050 increased from 50 percent in the business-as-usual scenario to a lower bound of 51 percent under the low-growth scenario and 97 percent under the high-growth and mandatory compliance scenarios. This results in a fiscal benefit range of between PV $0.3m and $32m.

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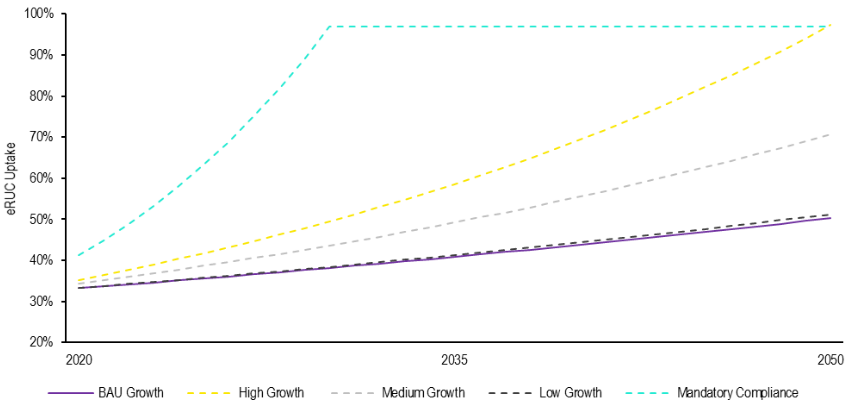
[333] Data provided by a Demonstrator Project.

Figure R06 – eRUC accelerated uptake scenarios trends



15.6.4.2 *Enablement of distance-based and real-time tolling*

Traditional revenue collection techniques for road investments (such as fuel excise duty and RUC) are reasonably blunt policy tools. The implementation of the SBAS signals has the potential to provide additional confidence to regulators in exploring alternative revenue collection models.

Specifically, it is anticipated that the achievement of lane-level and where-in-lane level accuracy will broaden the range of road pricing options available to government, should it ever be considered in the future. Moreover, it is anticipated that the level of accuracy offered by the SBAS signals will enable real-time road pricing, which is considered one of the most effective road pricing types in addressing congestion. This has the potential to result in reduced delays, increased travel time reliability, reduced emissions, and improved economic productivity.

More accurate location information allows the Government to consider options for potential pricing of other negative externalities where location is an important factor (e.g. location and timing is relevant to potential pricing of harmful emissions) or new ways to implement charges for the use of particular roads or regional networks (e.g. regional fuel tax). The SBAS signals might also enable Australia to consider opportunities around the implementation of eRUC systems.

15.6.4.3 *Enhanced mobility and accessibility for under-served populations*

Vehicle automation, enabled by the SBAS signals, can increase the mobility of currently under-served populations, which include non-drivers, those with travel restrictive medical conditions, and seniors.

A 2016 study[334] attempted to use the US Department of Transport (USDOT) data to identify the travel behaviours of the under-served populations, with an aim of establishing the expected upper bound of vehicle kilometres travelled as a result of 100 percent CAV uptake. Their calculations suggested an upper bound increase of 14 percent over existing VKT across under-served populations, which was broadly consistent with numerous other studies. Given the reliance on Level 4–5 automation to achieve the accessibility improvements, this benefit has been limited to a qualitative analysis due to uncertainty surrounding full implementation of CAVs.

15.6.4.4 *Lowering of market barriers for safety applications*

Discussions with sector experts suggest that Australia and New Zealand currently have access to the full array of safety applications available internationally. However, they have also suggested that the risk of preclusion may increase two to three years from now as technology uptake rapidly increases in the sector and innovations may or may not rely on the SBAS signals. Therefore, deployment of the SBAS signals will enable both the Australian and New Zealand market to remain flexible and open to new SBAS signal-reliant C-ITS safety applications, which will work towards improving overall health and safety outcomes.

15.6.4.5 *Mapping efficiencies*

Maps are an important tool for the road sector as a way of improving navigation, optimising the transport network, and improving overall network efficiency. Currently, map makers deploy vehicles across the transport network to collect accurate measurements and images of the real world using surveying and camera equipment. This data is then used for digital map development and maintenance applications. A sample of these applications include adjusting road centrelines, capturing new roads or road changes, capturing road widths, heights and curvatures, geo-referencing road signs, and capturing the characteristics of different road signs.

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[334] Harper, C. et al (2016) Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. Transport Research Part C: Emerging Technologies, Volume 72, November 2016, Pp 1-9. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0968090X16301590

All data captured by map providers are geo-referenced and input into a master map for reference by vehicles as they navigate any given environment. Discussion with the sector suggests that the greater spatial resolution afforded by the SBAS signals may remove the need to cross-reference collected data against ground reference stations, thereby removing a post-processing step in the overall map building process. More specifically, it is anticipated to:

- Reduce the quality check requirement on post-processed results
- Reduce map processing times (which is a non-labour activity)
- Reduce cloud processing service and associated costs
- Reduce the risk of further collection exercises required where post-processing yields unsuitable results
- Potentially avoid associated subscription costs to use reference stations.

Given that most of the tasks noted above are automated, labour time savings are anticipated to be minor, with less than one percent of total map production hours anticipated to be saved. Nevertheless, these minor efficiency improvements serve as first steps for future self-healing maps (discussed in the next section), which may serve as important tools for CAVs.

15.6.4.6 Enabling self-healing maps for CAVs

An additional benefit identified through discussion with the sector is the potential for the SBAS signals to serve as one of many enablers for self-healing maps, that is, maps which undertake dynamic and rapid corrections. For example, a map could automatically update to show a fallen tree, unplanned roadworks, or a road blockage resulting from an accident. Maps without current information pose an inconvenience to manual drivers but become increasingly critical as vehicles become more automated and rely on accurate maps that include road condition and flow as one input into their inputs for route planning and hazard avoidance.

The SBAS signals can support reduced post-processing times for these maps, but the implementation of the maps requires other equipment and processes. Vehicles need to be equipped with high-definition mapping software which can carry out dynamic rapid corrections. This may require significant policy and regulatory intervention.

Overall, those spoken to in the sector agree that there remain many unknown variables at this stage to perform a reasonable quantifiable analysis, as many other components must meet certain technological thresholds for self-healing maps, and CAVs, to come to market. The deployment of the SBAS signals serves as one enabler, but certainly not the only enabler, required to unlock the benefits noted.

15.7 Summary

Table RO12 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning. The SBAS signals are anticipated to generate a **PV AUD$1.1b** economic impact across the Australian and New Zealand road sector over a 30-year period.

Table RO12 – Benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Improved journey times via enablement of CAVs	Requires lane level accuracy	No base case due to technology being new	Enhanced network efficiency resulting in $760m saving	L1, DFMC, PPP
Decreased collision risk via enhanced C-ITS safety applications	Sub-metre accuracy unlocks a large portion of available applications	Variety of LiDAR, standalone GNSS, DGPS, radars and cameras	45 fatalities and 2,800 serious injuries avoided, resulting in $277m saving	L1, DFMC, PPP
Improved journey times via C-ITS signal priority applications	Requires lane-level accuracy	Currently uses standalone GNSS which is inefficient	28% reduction in network delays resulting in $46m saving	L1, DFMC, PPP
Reduction in RUC administrative costs	Requires road level – lane level accuracy	Standalone GNSS (plus other information sources)	Hypothetical savings of $0.3m to $32m via enablement of lower cost eRUC	L1, DFMC
Enablement of distance-based and real-time tolling	Requires lane level accuracy	No base case due to technology being new	Enhanced network efficiency	L1, DFMC
Enhanced mobility and accessibility for under-served populations	Requires lane level accuracy	No base case due to technology being new.	14% increase in VKTs for the under-served population	L1, DFMC, PPP

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Lowering of market barriers for safety applications	Sub-metre accuracy unlocks a large portion of available applications	Variety of LiDAR, standalone GNSS, DGPS, radars and cameras	Enablement of wider array of C-ITS safety applications which could save more lives	L1, DFMC, PPP
Mapping efficiencies	Requires lane level accuracy	Local sensors, standalone GNSS, and correction services	Reduction in post-processing times for maps	L1, DFMC, PPP
Enabling self-healing maps for CAVs	Decimetre	No base case currently	Real-time maps for use in sensor integration mapping for CAVs	PPP

A range of additional applications in the road sector have been identified throughout this research but have not been quantified (or described qualitatively) for a range of reasons[335]. A collection of these applications is provided in the additional applications Chapter 18.

15.8 Assumptions and limitations

Initial research and discussion with experts within the road sector suggest that there remain quite a few unknowns in both the current and future markets for C-ITS and CAVs. However, there is broad agreement that despite these unknowns, it remains important to explore the potential benefits of C-ITS and CAVs in order to ensure that the road ecosystem in Australia and New Zealand is flexible and conducive to future safety and efficiency applications.

In undertaking this benefit analysis exercise, EY has relied upon empirical research, official statistics, or sectoral expertise to underpin key figures, such as uptake rates, C-ITS effectiveness, and crash figures. It is acknowledged that in many instances these studies relate to geographical areas and transport systems that may present different characteristics to those that are the focus of this analysis. However, in the absence of more relevant information, these studies are considered appropriate.

In addition, to standard caveats around economic modelling, the following assumptions and limitations are worth highlighting:

Present value discount

All quantitative benefits have been discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

C-ITS effectiveness

Austroads has developed a C-ITS effectiveness range of 52 to 72 percent. It has been assumed that the effectiveness[29], or success rate, of C-ITS safety applications is strongly correlated with vehicle automation. As vehicles ascend the levels of automation towards Level 5 automation, it has been assumed that C-ITS effectiveness increases from 52 to 72 percent and beyond.

CAV automation uptake

The following adoption rates have been assumed for Level 4-5 CAVs: 2030 – 25 percent penetration, 2040 – 50 percent penetration, 2050 – 75 percent penetration, and 2060 – 100 percent penetration.

C-ITS component assumptions

It is assumed that there are only six key components within a C-ITS: sensors, automated controls, software, servers and power supplies, wireless networks, and positioning. Further, it is assumed that there are five methods to fulfil the positioning component: the SBAS signals, DGPS, RTK, commercial PPP, and standalone GNSS.

AV component assumptions

It is assumed that there are only 11 broad components to CAVs: vehicle, cyber security, V2V and V2I communication, automation, auto repair, tyres, positioning, safety mechanisms, battery, hardware, and engine. It is assumed there are four alternative positioning techniques for the CAV absolute positioning requirement: the SBAS signals, RTK, standalone GNSS aided by sensors, and sensor integration.

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[335] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

Average journey time assumption

Average Australian journey speeds have been assumed to be similar to New Zealand average speeds of 50 kilometres per hour.

Value of time assumption

Value of time assumed to be AUD$42 for Australia, based on Australian Transport Assessment and Planning data, and NZD$33 for New Zealand, based on NZ Transport Agency Economic Evaluation Manual data.

Spatial sector

Key findings

The spatial sector provides highly accurate and precise positioning information to other economic sectors and ensures that this information is fit for purpose. The sector consists of primary activities around aerial, land, and hydrographic surveying, which provide value across all spatially enabled sectors of the economy.

Highlights

The spatial sector can potentially accrue direct economic benefits due to the presence of the SBAS signals. In particular:

- An estimated 50 percent of New Zealand (by land mass) and 75 percent of Australia (by land mass) lack mobile phone coverage widely relied upon for GNSS positioning corrections across the surveying, agriculture, and construction industries. The SBAS signals are assumed to complement the existing CORS networks to deliver precise positioning services to remote areas and mobile phone blackspots.
- The improved accuracy delivered by the SBAS signals has the potential to allow low accuracy, rural cadastral (Class C) surveys to be conducted by a single surveyor. This can potentially reduce the operating cost to complete all Class C surveys in New Zealand by roughly NZD $185,000 per annum.
- The performance of SBAS signals is anticipated to play a role in reducing the costs of capturing aerial imagery and reducing the requirement for surveyed ground control points. The extent to which SBAS plays this role is dependent on a range of factors including the size of the land mass requiring imagery and the specific cost structure of supporting UAVs. Initial estimates suggest that operating costs can be up to 50 percent cheaper in certain conditions.

Additionally, it is noted that the SBAS signals can enable the spatial sector to support economic benefits in other sectors including:

- Better detection of crop diseases and depiction of crop health in a wide range of agriculture sub-sectors (including horticulture and broadacre).
- Increased use of remote audit activities for work done on construction sites. The use of UAVs and high-resolution imagery can improve site productivities and prevent employees from needing to conduct survey activities from heights in certain instances.

The specific benefits of these two examples are provided in the agriculture Chapter and the construction Chapter respectively.

16. Spatial sector

16.1 Sector description

The spatial sector provides vital services to other industries including land development, mining, and agriculture, primarily relating to aerial, land, and hydrographic surveying activities.

The positioning accuracy requirements of the spatial sector are some of the most demanding of all sectors considered in this report. The cadastral systems used in Australia and New Zealand require a centimetre-level accuracy to delineate property boundaries and services, which must be certified by a licensed surveyor. Some survey activities have less stringent regulations and may accept accuracies at the decimetre level, depending on location and the required information[336].

The spatial sector has been an early adopter of augmented GNSS. For example, surveyors currently use augmented GNSS in combination with other specialist equipment to capture the accurate location of points in setting out engineering and other infrastructure projects. In a direct sense, the use of augmented GNSS can save on labour costs, reducing the number of surveyors and technical staff required on-site.

The spatial sector can also generate a range of indirect benefits, particularly when coupled with other emerging technologies and processes. This enabling role is often critical for economic benefits to accrue in other sectors (such as operational productivity and reduced capital expenditure). For example, UAVs equipped with reliable positioning systems, cameras, and mapping software can provide significant operational productivity benefits to the agriculture sector.

16.2 Use of positioning technology

As with all other sectors, the use of positioning technology in the spatial sector varies depending on the application. To support the descriptions of benefits later in this Chapter, the use of positioning technology in this sector has been broken down into three sub-sectors that align to the scope of the four Demonstrator Projects. It is acknowledged that in practice the spatial sector is considerably broader than these three sub-sectors.

Positioning infrastructure networks

Regional and national governments regularly invest in positioning infrastructure to provide utility to those within their geographic boundaries. Both Australia and New Zealand own and operate a widespread network of CORS, providing network RTK services and reliable data for use across all sectors of industry[337].

In simple terms, CORS networks provide corrections that allow the users to achieve centimetre-level positioning in real-time to determine the position of a user relative to a network of CORS. A range of supporting activities, including the provision of raw data streams and post-processing services, is also an inherent part of such a system.

The density of these CORS networks, and the level of supporting infrastructure (such as mobile coverage), is an important factor in the level of positioning performance available within a jurisdiction. It is commonplace for there to be transmission blackspots resulting in no signal access. This clearly results in performance that is worse than could be expected if there were no blackspots.

Cadastral surveying

Cadastral surveys are a sub-sector of surveying that determines legal property boundaries. These surveys underpin processes of land transfer, registration, and classification[338].

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[336] ACIL Allen (2013) Precise positioning services in the surveying and land management sector: an estimate of the economic and social benefits of augmented positioning services in the surveying and land management sector. Retrieved from: http://www.crcsi.com.au/assets/Resources/6db084dc-9a94-439a-8911-ba93ee41f455.pdf

[337] For example, DFSI – Spatial Services operate the CORSnet-NSW network, The Victorian Department of Land, Water and Planning operate the GPSNet network, and Land Information New Zealand are responsible for the PositioNZ network.

[338] Anderson, J. and Mikhail, E. (1998) Surveying: theory and practice.

There are currently four classes of cadastral surveying in New Zealand[339]. These are presented below in descending order of accuracy requirement:

- **Class A:** Urban, intensive commercial, industrial, or residential purposes.
- **Class B:** Rural, residential or moderate commercial, industrial, or residential purposes.
- **Class C:** Rural, non-residential properties where precise boundary determination is non-essential (i.e. high-country farm). Class C boundaries are permitted for determining new boundaries.
- **Class D:** Rural, special circumstances when boundary surveying is challenging (i.e. very mountainous or variable terrain).

Current rural surveying techniques are labour intensive and can involve travelling large distances over the course of a project. It is commonplace to spend a significant amount of time moving the team and their equipment between points of interest, highlighting the possibility of using augmented GNSS signals to complete more of these activities autonomously.

Cadastral surveying requirements in Australia (at a state and federal level) are not consistent with these definitions. For example, Victoria does not have surveying classes as such, rather there are specific requirements depending on the use case (various sizes of subdivision, single block etc)[340].

High-resolution imagery

A range of economic sectors currently utilise high-resolution imagery in day-to-day activities or are developing the capability to do so. For instance, the horticulture industry could benefit from high-resolution imaging of crops to determine key markers of economic productivity such as vine health and nutrient levels of surrounding soils.

Positioning capabilities are important requirements of high-resolution imagery systems by providing accurate geo-referencing.

The presence of positioning technologies alone is not sufficient to enable improvements in economic productivity associated with high-resolution imagery. Systems also require additional components such as high-resolution imaging cameras and software to process this information into useful outputs such as yield maps.

16.3 Demonstrator Project descriptions

Four Demonstrator Projects were commissioned to investigate the potential benefits of the SBAS signals in the spatial sector.

There are some difficulties associated with defining terms used across multiple sectors of industry, given the increasing reliance on spatial data and widespread use of emerging technologies such as UAVs. A project-wide decision was made to include the following projects in the spatial sector given their enabling characteristics – but it is acknowledged that certain characteristics could also be included in other sector Chapters. Cross-referencing across Chapters has been undertaken to minimise the impact of this definitional ambiguity.

Further details of these Demonstrator Projects are contained in Table SPA1.

Table SPA1 – Spatial sector Demonstrator Projects

Demonstrator project	Description	Signals tested
DELWP/RMIT	Understand whether the SBAS signals can provide a fill-in service in remote locations or mobile phone blackspots in Victoria where RTK/Network Real Time Kinematic (NRTK) based on a CORS network is not available.	L1, DFMC, PPP
DFSI - Spatial Services	Understand whether the SBAS signals can provide a fill-in service in remote locations or mobile phone blackspots in NSW where RTK/NRTK based on a CORS network is not available.	L1, DFMC, PPP
University of Otago	Evaluate the effectiveness of conducting low accuracy, rural cadastral surveys using the SBAS signals.	L1, DFMC, PPP

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[339] Information provided by a Demonstrator Project. Additionally, these requirements are outlined in: Land Information New Zealand (2017) Rules for cadastral survey 2010. Retrieved from: https://www.linz.govt.nz/regulatory/tbc

[340] Department of Environment, Land, Water and Planning (2018) Victorian cadastral surveys practice directives. Retrieved from: https://www.propertyandlandtitles.vic.gov.au/surveying/advice-and-guidelines-for-surveyors/victorian-cadastral-surveys-practice-directives

Demonstrator project	Description	Signals tested
University of Tasmania	Evaluating the application of the SBAS signals for the precise positioning of UAVs and direct geo-referencing of sensor data in precision agriculture.	L1, DFMC, PPP

16.4 Anticipated benefits

A benefits mapping exercise was first undertaken with each Demonstrator Project to identify how the benefits of the SBAS signals could flow through to operating changes in the future. This led to the identification of the following potential operational benefits.

It is important to note that some of these benefits accrue across multiple Demonstrator Projects within the spatial sector. Moreover, some of these benefits are also present across Demonstrator Projects in other sectors. However, for the purposes of this Chapter, the following benefits accrue exclusively to the spatial sector applications.

Additionally, section 16.7 provides a high-level indication of where some of the benefits in the spatial sector overlap with benefits identified in other sector Chapters.

Extending coverage of existing positioning networks

Real-time access to positioning services is often limited to areas with sufficient mobile phone coverage to maintain connection to the internet. In remote areas and mobile phone blackspots such positioning services are typically not available, even if CORS stations exist[341].

Whilst the operational coverage of positioning networks (such as those operated by DFSI – Spatial Services in NSW and DELWP in Victoria) is defined by the extent of the positioning infrastructure (coverage and density of reference stations), practically this is limited by mobile network reception.

It is anticipated that the SBAS signals will enhance and complement existing positioning networks by providing better coverage in areas where there may be mobile blackspots. This will benefit current and future users of the CORS/RTK/PPP-RTK/NRTK services.

There could also be benefits for deferred/reduced investment in core network infrastructure such as reference stations on the back of this operational enhancement.

Reducing labour requirements of cadastral surveys

Currently, most if not all cadastral surveying is undertaken by trained surveyors[342]. This can be an expensive undertaking, particularly in rural environments when surveyors are required to traverse significant distances to determine property boundaries.

Being able to reduce some of the labour requirements associated with certain cadastral surveys is possible through utilisation of the SBAS signals.

Reduced operating costs for aerial imaging

The use of UAVs to conduct aerial imaging is increasing in a range of sectors, most notably agriculture. This imagery is used to determine crop and soil condition as well as other in-field information (e.g. weed location).

Key factors in the uptake of aerial tasks include the operating costs of the UAV, as well as the costs associated with establishing ground control points (GCPs). GCPs are marked points that have been assigned a known geographic location and can be used to differentiate and combine photographic data within the survey area.

The operating costs of aerial imaging using UAVs currently stand to benefit from the SBAS signals, particularly when there are no GCP requirements for a given survey. The cost of collecting even minimal ground control information adds a significant cost to every UAV aerial survey.

Anticipated benefits for the spatial sector have been classified into the benefit categories in Table SPA2.

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[341] Information provided by a Demonstrator Project.

[342] In both Australia and New Zealand, cadastral surveys can only be undertaken by a licensed cadastral surveyor or a person acting under the direction of a licensed cadastral surveyor. Retrieved from: https://www.linz.govt.nz/land/surveying

Table SPA2 – Spatial sector benefit categorisation

Benefit	Benefit category	Quantitative?
Extending coverage of existing positioning networks	Operating expenditure savings	No
Reducing labour requirements of cadastral surveys	Operating expenditure savings	No
Reduced operating costs for aerial imaging	Operating expenditure savings	No

16.5 Positioning needs and current methods

As mentioned earlier, the positioning requirements of the spatial sector are some of the most stringent of any sector. Given the specific nature of the three benefits identified, a separate description of the positioning needs and current methods is provided below.

16.5.1 Extending coverage of existing positioning networks

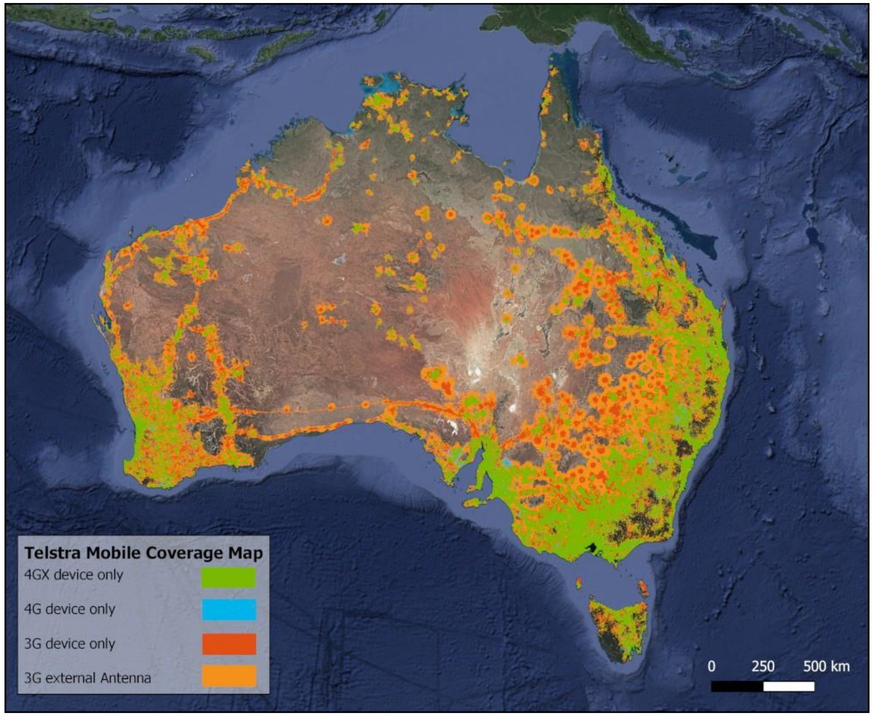
It is not expected that the SBAS signals will replace existing positioning networks. Particularly because many of the users of these networks have an expectation for positioning performance that is greater than what the SBAS signals can provide (for example, surveyors frequently require centimetre-level accuracy).

However, it is noted that CORS-based positioning services typically depend on mobile coverage. For example, whilst DELWP can provide a service state-wide, if there is no mobile phone coverage then essentially there is no access to the CORS network even though the service is technically available in these areas[343].

In New Zealand it is estimated that mobile networks currently cover over 95 percent of New Zealand's population. However, on a geographic basis, coverage is currently sitting at around 50 percent of New Zealand's land area[344].

In Australia, the three national mobile network operators collectively claimed to provide mobile coverage to 99 percent of the population (i.e. premises). However, reflecting Australia's highly urbanised population, this level of coverage equates to only around 25 percent of the landmass[345]. A visualisation of the estimated mobile network coverage across Australia is provided in Figure SPA1[346].

Figure SPA1 – Visualisation of mobile network coverage (Australia)



It is therefore expected that in some circumstances, the SBAS signals will be able to provide positioning services in environments that are currently outside the mobile coverage areas. In this sense, SBAS is complementary and will have the potential to 'fill the gaps' of the existing service delivery platform.

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[343] There remains the option to use satellite communications (VSAT) to deliver the service in remote areas, but this is uncommon.
[344] Crown Infrastructure Partners (2018) What is the Mobile Black Spots Fund (MBSF)? Retrieved from: https://www.crowninfrastructure.govt.nz/blackspots/what/
[345] Department of Communications (2013) Mobile coverage programme: discussion paper. Retrieved from: https://www.communications.gov.au/have-your-say/mobile-black-spot-programme-discussion-paper
[346] Image provided by FrontierSI. This has been developed utilising data available on Telstra's Australian mobile network.

16.5.2 Reducing labour requirements of cadastral surveys

Current Class C surveying in New Zealand is generally completed by a single surveyor or a team of two trained surveyors, using total stations, levels, and other specialised equipment. This can involve significant travel times, meaning staff and transport costs dominate rural surveying operating costs.

Discussions with a Demonstrator Project, as well as interpretation of Surveyor General Guidelines, suggest that the positioning requirements for Class C surveys are expected to be between 20 centimetres and 50 centimetres[347].

Time intensive rural surveying processes have high man hour costs, mainly spent on driving and covering the specific terrain. Given the (often) remote nature of Class C rural surveys, this is often done on foot, which can be time inefficient.

The positioning requirements in Australia are different to New Zealand owing to different definitions of analogous activities. As noted earlier, in Victoria positioning requirements are based on use cases rather than demarcated into Classes.

The positioning requirements of these use cases vary by use case, but the differences between two RTK measurements should not exceed 0.05 metre and a check on a ground marks should not exceed 0.1 metre[348].

These requirements therefore imply that in an Australian context, the SBAS signals are not expected to meet the required performance standards and hence result in reduced time for cadastral surveying.

16.5.3 Reduced operating costs for aerial imaging

There are two core components of UAV-related aerial surveying that have a strong reliance on positioning:

UAV

It is common for augmented GNSS-enabled UAVs to be deployed for aerial surveys in order to meet the common requirement for accurate positioning, especially in industries such as construction where UAVs are expected to navigate through congested operating environments (for example near the facades of buildings).

In the agriculture sector, the desire for shorter convergence times can be an important expectation. For example, information provided by a Demonstrator Project suggests that aerial imaging in expansive environments often requires multiple passes which means that the UAVs must periodically dock and allow sufficient time to wait for appropriate signal convergence.

Convergence time in this instance directly relates to operating cost as there are limited productive activities that UAV operators can be undertaking while they wait for the signal to converge.

Imaging

Ideally images need to be able to achieve high enough resolution so that if these images are overlaid in a time series, individual crops (and agricultural conditions) can be identified and tracked.

The specific positioning requirements will be crop dependent, but to satisfy the resolution requirements for aerial imaging of high-value agricultural crops, positioning services should be capable of delivering sub-decimetre performance. Horticultural crops for example are assumed to benefit from sub-metre SBAS signal performance.

A Demonstrator Project notes that some agricultural work does not require such high levels of accuracy (e.g. a quick overview map of the performance of a crop does not necessarily need high spatial accuracy). However, for such a case, current standalone GNSS grade solutions are often sufficient[349].

16.6 Sector benefits

The following sections detail the benefits of the SBAS signals relative to the status quo, describe the anticipated economic impact, and estimate how benefits are attributed across the three signals. Unlike all other sectors represented in the Demonstrator Trial, the spatial sector is not expected to accrue any material economic benefits in its own right.

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[347] Land Information New Zealand (2009) Standards for tiers, classes, and orders of LINZ data.

[348] Department of Environment, Land, Water and Planning (2018) Victorian cadastral surveys practice directives. Retrieved from: https://www.propertyandlandtitles.vic.gov.au/surveying/advice-and-guidelines-for-surveyors/victorian-cadastral-surveys-practice-directives

[349] Information provided by a Demonstrator Project.

It is expected that a range of other sectors will benefit from enhanced positioning performance provided by SBAS signals, but these will not result in significant benefits to the spatial sector per se.

Accordingly, while efforts have been made to quantify some of these benefits to give a sense of scale and magnitude, none of these estimates have been officially carried through into the final quantifiable assessment of the economic benefits of the SBAS signals.

16.6.1 Signal attribution

Table SPA3 details how the benefits accrue to each of the SBAS signals based on signal performance and the positioning needs of each of the anticipated benefits. The benefits in relation to the use of the SBAS signals in the spatial sector are expected to accrue across PPP, L1 and DFMC depending on the specific application.

These indicative test results have been provided by FrontierSI as representative of the testing carried out by the SBAS Demonstrator Projects in this sector. The testing was carried out in open sky environments with mid-range equipment. Values presented are at a 95 percent confidence interval.

Table SPA3 – Spatial sector signal attribution

Signal	Spatial sector test results	
	Expected horizontal performance (m)	Expected vertical performance (m)
L1	0.9	1.4
DFMC	1.0	1.5
PPP	0.1	0.2

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Qualitative benefits					
Extending coverage of existing positioning networks	Varied	✓	✓	✓	Greater coverage desirable. It is expected that the accuracy requirements (and possibly convergence times) will still not be sufficient for many surveying activities.
Reducing labour requirements of cadastral surveys	Decimetre	-	-	✓	Accuracy requirements mean a focus on PPP
Reduced operating costs for aerial imaging	Varied	✓	✓	✓	Different requirements depending on application but PPP expected to be most relevant

16.6.2 Uptake rate

Because the economic benefits in this Chapter have not been quantified, a formal confirmation of expected uptake has not occurred. However, it is assumed that uptake in the sector will differ by application with the following being the reasonable assumptions considered:

- Extending the coverage of positioning networks could see a strong uptake in early years as the SBAS signals are likely to be complementary to existing networks. However, it is assumed that this uptake would plateau over time, particularly as mobile networks continue to be rolled out.
- Enabling non-surveyors to complete Class C cadastral surveying activities in New Zealand and reduced operating costs for aerial imaging would be likely to have an uptake curve more akin to an S-curve over a longer time period. It is anticipated that in both instances, the SBAS signals (in terms of accuracy and convergence time in particular) would need to provide better performance before uptake really started to improve.

16.6.3 Qualitative benefits

No quantitative assessment of the economic benefits of an operational SBAS could be completed by the relevant Demonstrator Projects. This is partially a result of the lack of relevant information but also a result of potential double-counting across other sectors. However, a range of economic benefits have been presented qualitatively throughout the remainder of this Chapter.

16.6.3.1 Extending coverage of existing positioning networks

The SBAS signals are expected to benefit a range of applications by complementing CORS-based RTK/PPP-RTK/NRTK services in remote areas and mobile phone blackspots where mobile phone coverage is intermittent or non-existent.

Users of the current positioning networks are varied, but predominantly focus on surveying, agriculture, and construction. Information provided by a Demonstrator Project shows that 92 percent of current users fit within these three categories[350].

The present performance of the SBAS signals is likely to be insufficient to outperform commercial solutions in the surveying sector but it is expected there will be a range of additional users (most likely in the agriculture and construction sectors) that will see benefits from this increased coverage.

Increasing the number of users is not just beneficial for the users, but can also provide positive network effects for the network operators.

Additional users of the CORS network essentially provide additional subscription revenues to parties like DELWP and DFSI – Spatial Services to enable them to further invest in the network.

To the extent that CORS networks are based on a subscription model, this additional revenue can potentially increase the density, coverage, and enhancement of CORS networks, which can also result in performance improvements for current and future users of the service.

Similarly, it is possible that commercial providers may also benefit from increased subscriptions in instances where the greater coverage enables a better product to be sold (although this may be offset by fewer users needing NRTK).

16.6.3.2 Reducing labour requirements of cadastral surveys

Based on preliminary work, a Demonstrator Project expects improved efficiency and reduced cost for surveyors conducting low accuracy rural surveys by allowing Class C surveys.

No quantitative assessment of the benefits of extended coverage of positioning networks could be completed for this Demonstrator Project. However, an order and magnitude of savings is possible through the presentation of information provided by a Demonstrator Project.

Specifically, a Demonstrator Project indicated that between 50 and 75 Class C rural cadastral surveys are completed in New Zealand each year. It was also estimated that each survey would take between 25 and 37.5 hours to complete (with 75 percent of this time being office time). This results in over 2,000 hours per annum of surveying time.

It is assumed that the operating cost to complete all Class C surveys in New Zealand is roughly NZD $375,000 per annum. This is based on an average wage assumption of $120 per hour for surveyors and $60 per hour for assistants. It is also assumed that two surveyors (one surveyor and one assistant) is standard.

If the performance standards of the SBAS signals are achieved, then it is expected that comparable surveys may be undertaken by a single surveyor using one instrument without the need to set up a base station (i.e. single-baseline RTK) or conventional total station. This would have the theoretical effect of reducing operating costs by roughly NZD $185,000 per annum.

There will potentially be other costs associated with this saving (including the presence of fixed costs such as vehicle usage and fuel) but this gives an indication of the potential to the sector.

Relatedly, there may be a range of instances where others may be able to utilise the SBAS signals to undertake activities that require an understanding of property boundaries. For example, real estate agents, lawyers and farmers may be able to better understand the location of rural easement boundaries without the use of a surveyor. The extent to which this materialises in practice will depend on the ease of use of SBAS-enabled surveying techniques and levels of training required.

16.6.3.3 Reduced operating costs for aerial imaging

All content for this benefit category has been based on information provided by a Demonstrator Project.

To evaluate the economic benefits of SBAS for commercial UAV surveys several scenarios were costed based on an Australian UAV's current costing model. Two scenarios were considered:

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[350] Information provided by a Demonstrator Project.

Scenario 1

Create a multispectral image mosaic of an eight-hectare paddock at seven-centimetre resolution.

Scenario 2

Create a multispectral image mosaic of a 30-hectare paddock at seven-centimetre resolution.

In terms of ground control, each scenario has been costed based on the inclusion of:

- a standard GCP survey (10–12 GCPs per flight block)
- a check point GCP survey (six GCPs per flight block)
- no GCP survey (UAV positions used as control, direct geo-referencing).

In terms of on-board GNSS, three options were considered by the Demonstrator Project:

- On-board standalone-grade GNSS (in combination with accurate ground control)
- On-board RTK GNSS (using a correction service) – no GCPs required
- On-board SBAS compatible receiver – no GCPs required.

When no GCP survey is required (RTK and SBAS scenarios) cost savings were estimated to be approximately 50 percent. The exception to this is the 30-hectare SBAS-enabled option due to the wait required for convergence each time the UAV is moved to a new launch site. This is a significant cost and a major hindrance to logistical viability.

In scenarios where ground control is required, the additional cost in time and equipment hire costs compared to a typical UAV survey using an RTK-enabled UAV, is minimal (less than six percent). Moreover, the cost of an SBAS-enabled UAV survey with six GCPs is 10 to 13 percent higher than the standard scenario for a single flight survey and 35 to 38 percent higher when mapping 30 hectares. Again, this is mainly due to the cost (in wait time) for convergence.

It is acknowledged that the UAV pilot can use some of this time to undertake the GCP survey, but there is a strong chance there will be idle time before each flight.

If convergence time could be reduced to sub-15 minutes then the SBAS-enabled UAV could undertake the survey for a similar cost to an RTK-enabled UAV without the added overhead of a correction subscription (approximately $2,000 per annum).

16.7 Benefits to other sectors

Unlike any other economic sector covered through the Demonstrator Programme, the spatial sector is a critical service provider to enable other benefits to come to fruition. As an example, it is anticipated that the SBAS signals will increase the use and capability of UAVs (and associated high-resolution imagery) for operations such as surveying, tracking personnel and equipment, and undertaking audit activities in the construction sector.

Table SPA4 provides an indication of how relevant the spatial sector benefits are likely to be in other economic sectors.

Table SPA4 – Spatial sector signal attribution

Anticipated benefits	Spatial	Aviation	Agriculture	Construction	Consumer	Maritime	Rail	Resource	Road	Water utilities
Extending coverage of existing positioning networks	✓	✗	✓	✓	✗	✗	✓	✓	✓	✓
Reducing labour requirements of cadastral surveys	✓	✗	✓	✓	✗	✗	✗	✗	✗	✗
Reduced operating costs for aerial imaging	✓	✓	✓	✓	✗	✗	✓	✓	✓	✓

The evidentiary basis for this table has been taken from information pertaining to each Demonstrator Project. A brief description of this evidence is provided in the assumptions and limitations section of this Chapter.

It is important to note that a cross icon next to a benefit category/sector does not mean that no application exists, but rather, that evidence generated through this investigation did not expose such an example.

16.8 Summary

Table SPA5 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning for the spatial sector.

Table SPA5 – Benefits summary

Benefit	Positioning needs	Status quo	Anticipated benefits	Signal attribution
Extending coverage of existing positioning networks	Varied	Mobile coverage estimated to cover 50 percent of New Zealand's land mass and 75 percent of Australia's land mass.	SBAS signals anticipated to complement CORS-based RTK/NRTK services in remote areas and mobile phone blackspots.	L1, DFMC, PPP
Reducing labour requirements of cadastral surveys	Decimetre	Positioning requirements for Class C surveys are expected to be between 20cm and 50cm	Conducting Class C surveys by a single surveyor could reduce operating costs by roughly NZD $185,000 per annum.	PPP
Reduced operating costs for aerial imaging	Varied	UAV operation and imaging typically require ground control stations and augmented GNSS services.	When no GCP survey is required, cost savings may be 50 percent.	L1, DFMC, PPP

16.9 Key assumptions and limitations

The analysis undertaken for this sector has been based on a combination of official data sources, desktop research, as well as information provided by the Demonstrator Project. These inputs have all been agreed in discussion with the relevant Demonstrator Project and FrontierSI.

Scaling and quantification

The benefits of SBAS signals to the spatial sector have not been quantified, nor have they been scaled across Australia and New Zealand. This decision was made from a combination of the performance of the Demonstrator Trial for the projects in this sector as well as a lack of evidence that could be relied upon for scaling purposes.

A range of evidentiary bases were investigated to populate Table SPA4. These have been broken down by benefit category:

Extending coverage of existing positioning networks

Information provided by a Demonstrator Project showed that the following sectors currently utilise their positioning networks. An indication of the relevant proportion of total subscriptions is provided in parenthesis.

- Surveying (53 percent)
- Agriculture (32 percent)
- Construction (10 percent)
- Mapping (four percent)
- Receiver Independent Exchange Format (RINEX)[351] (one percent).

Reducing labour requirements of cadastral surveys

Information provided by a Demonstrator Project suggests that land-based rural cadastral surveying activity could stand to benefit the most from the SBAS signals. Accordingly, a narrow set of land-based sectors that would rely on rural cadastral surveys would also stand to benefit from this activity.

Reduced operating costs for aerial imaging

Information provided by a Demonstrator Project, coupled with information gathered in completing other sector Chapters, suggests that there is a wide

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[351] This category includes those users who require raw data.

range of potential applications for high-resolution imagery. Two examples of this include:

- *Agriculture*: Disease can have a negative impact on plant health, and ultimately lead to crop loss which can adversely impact on yield. Discussion with sector experts suggests that farmers could minimise negative impacts on their farms by detecting disease early and in the right locations by utilising UAVs. The specific role of positioning technology is in identifying the spatial position of diseases via accurate geo-referencing of aerial imagery, which is considered a critical enabler of disease detection. This application is described in more detail in the agriculture Chapter.
- *Construction:* It is anticipated that the SBAS signals will increase the use and capability of UAVs for operations such as surveying, tracking personnel and equipment, and undertaking audit activities. It is anticipated to improve site productivities and prevent employees from needing to conduct survey activities from heights in certain instances. This application is described in more detail in the construction Chapter 10.

Water utilities sector

Key findings

The utilities sector covers provision of electricity, telecommunications, gas, and potable water to businesses and customers, as well as the removal of waste water and management of storm water. The provision of infrastructure is essential to the quality of life of people in the home and supports the effective running of the workplace.

Highlights

Total benefits of **PV AUD $277m** are anticipated as a result of the deployment of SBAS signals (namely PPP) in the water utilities sub-sector, which includes potable water, storm water, and wastewater, over a 30-year period. These benefits consist of:

- **Contribution towards a reduction of 140,000 accidental strikes in the water utilities sub-sector.** This benefit accrues to the ability of non-specialist users to capture accurate asset information when services are exposed or newly laid, and when coupled with a democratisation of the information can lead to prevention of future accidental strikes. This benefit will then result in:
    - A reduction in direct capital expenditure costs of PV $18m over a 30-year period.
    - A reduction in indirect economic impacts across other sectors of the economy of **PV $259m** over a 30-year period.
- **Reduced delay in underground asset digging** may occur as the ability to mark out the location of underground assets faster will reduce required post-processing of data and reliance on expensive expertise and equipment.
- **Reduction in surveying costs** is anticipated that wider accessibility to precise surveying will reduce reliance on in-demand specialised surveyors and surveying equipment.

It is worth noting that this quantifiable analysis has been limited to the water utilities sub-sector due to information availability. It is anticipated that the scale and magnitude of these benefits will be considerably higher than those presented.

Quantifiable benefits

Figure WU1 – Benefits by benefit category (30-year, AUD)

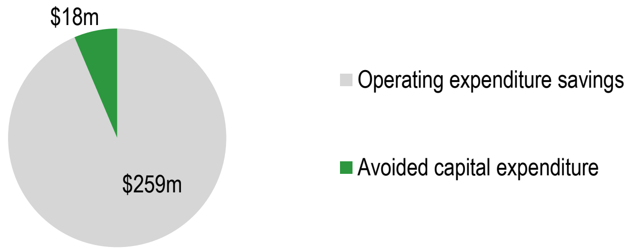


Figure WU2 – Benefits by geography (30-year, AUD)

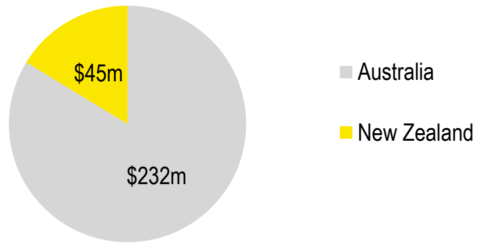
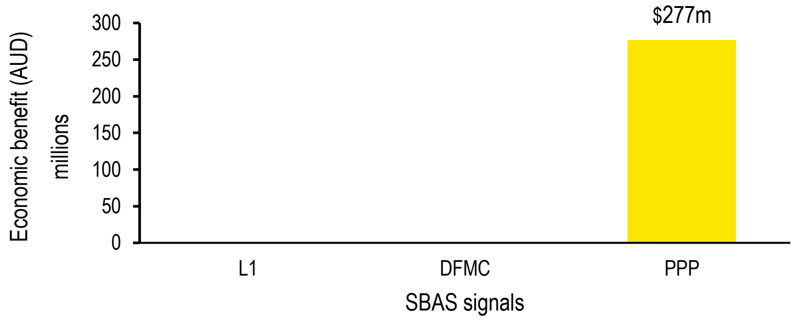


Figure WU3 – Benefits by signal type (30-year, AUD)



17. Water utilities sector

17.1 Sector description

The utilities sector covers provision of electricity, telecommunications, gas, and potable water to businesses and customers, as well as the removal of waste water and management of storm water[352].

The utilities sector is an essential component of both the Australian and New Zealand economies, enabling businesses to operate and supporting the quality of life of people both in the workplace and at home.

The utilities sector is characterised by a large asset base of pipes, cables, and associated infrastructure. In many instances, these assets are buried underground and so it is not easy to determine precise location and state of the asset. Performing asset maintenance checks is an important task but is often a costly exercise for the operator and a disruptive exercise for those near the worksite.

Additionally, it is important to emphasise the systemic nature of infrastructure assets. Depending on criticality of the chain and the reliance on core transmission assets, disruption to one part of the network can have profound impacts on other parts of the network as well as the wider economy.

For the purposes of this assessment, it is important to note that the quantitative assessment has been limited to just an assessment of the water utilities sub-sector[353] due to data limitations. However, it is expected that the general findings in this Chapter will be likely to apply to a greater or lesser extent to all other utility types. This assumption is drawn because many of the same characteristics exist between utility types – underground, linear, network assets – even if the specific positioning requirement differ in practice.

17.2 Use of positioning technology

The utilities sector is generally capital intensive. Efficient management of infrastructure, plant, and equipment is one of the most critical functions of its operation. Information on the location, status, and functionality of these assets is considered fundamental to operations, and as such, has given rise to the use of GIS and related survey quality data[354] within the sector[355].

Currently, there are two main areas of operation which benefit from survey quality data within the sector:

- Design and construction
- Asset management.

With regards to the former, GIS is commonplace in planning and design processes. Surveying technologies increasingly rely on standalone GNSS to produce route plans, identify the location of surrounding infrastructure (especially underground), and prepare the base maps on which designers can determine their route decisions.

Asset management within the utilities sector generally refers to management of assets such as transmission and distribution systems, dams, reservoirs, power stations, water treatment plants, and control systems[357]. Currently, accurate positioning is utilised along with many other remote sensing and reporting systems to monitor the operating status of assets and control systems, identify faults, and manage maintenance programmes and investment decisions.

Obtaining position information across both asset management and design and construction activities is considered significantly easier for above ground assets, compared to underground assets.

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[352] http://www.investorwords.com/12443/utilities_sector.html

[353] Potable water, wastewater and storm water.

[354] Survey quality data in this context refers to positioning information that would be expected from surveying activity. Typically, this is in relation to five centimetre level accuracy, horizontally and vertically, although certain activities may need performance levels that are slightly better or worse than this benchmark.

[355] ACIL Allen Consulting (2013) Precise positioning services in the utilities sector: an estimate of the economic and social benefits of the use of augmented positioning services in the utilities sector. Retrieved from: http://www.ignss.org/LinkClick.aspx?fileticket=h5iRKR7fdUo%3D&tabid=56

A wide variety of surveying technologies are currently used to serve the accurate position requirements of underground assets including RTK, high-resolution cameras, radio frequency identification (RFID) markers, and LiDAR[356], as well as locating equipment such as ground penetrating radar (GPR) and electromagnetic locators (EML).

It is important to note that mapping is often undertaken by organisations and/or utility providers that have a clear interest in their own assets and use their own standards. Accordingly, there is often no common view of where all utilities are at a given time. This often presents issues around information asymmetries for councils when they attempt to map out their entire asset network. This may also lead to confusion for the public when they receive information from the utility owners before commencing work within their property.

17.3 Demonstrator Project descriptions

One Demonstrator Project was commissioned to investigate the potential benefits of the SBAS signals to the utilities sector. The Demonstrator Project trialled the PPP signal to determine whether it provided a sufficient level of service and improvements in accuracy, timeliness, and accessibility to benefit operational behaviour. Further details are provided in Table WU1. L1 and DFMC weren't tested given the accuracy requirements in particular were not expected to be sufficient for the purposes of accurately locating underground assets.

Table WU1 – Water utilities sector project description

Demonstrator project	Description	Signals tested
Orbica/Reveal Infrastructure	Exploring the potential of PPP to enable improvements in the accuracy, timeliness, accessibility, and affordability of accurate asset management data.	PPP

17.4 Anticipated benefits

In attempting to understand the material economic benefits anticipated from utilisation of the SBAS signals, a benefits mapping exercise was undertaken with the Demonstrator Project to identify how the positioning performance of the SBAS signals flowed through to operational benefits. This led to the identification of three operational benefits:

Reduction in accidental strikes

Wider availability of PPP is anticipated to enhance coverage of accurately mapped underground assets thereby reducing the risk of accidental strikes. The essence of this benefit is that greater accessibility to PPP enables a greater number of people to accurately map assets (such as contractors who are not surveyors), and if uploaded to an open data platform, adds to a growing archive of mapped assets. This phenomenon is referred to as the 'democratisation of data' throughout this assessment.

An improved understanding of underground asset locations by the sector, and the general public, has the potential to reduce accidental strikes and the corresponding direct repair costs borne by operators. A reduction in accidental strikes also has potential to reduce network downtimes and corresponding downstream impacts across the wider economy (indirect costs).

It is acknowledged that this benefit category is likely to occur over a long-term time horizon as information is likely to be most cost-effectively uploaded when underground assets are uncovered. This activity is an expensive exercise involving a range of techniques including GPR and EML to locate the asset and therefore would be likely to occur only as part of planned maintenance programmes, because of an unplanned maintenance event, or as part of related or contiguous works.

Reduced delay in underground asset digging

The ability to mark out[357] the location of underground assets faster will reduce required post-processing of data and reliance on expensive expertise

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[356] ACIL Allen Consulting (2013) Precise positioning services in the utilities sector: an estimate of the economic and social benefits of the use of augmented positioning services in the utilities sector. Retrieved from: http://www.ignss.org/LinkClick.aspx?fileticket=h5iRKR7fdUo%3D&tabid=56

[357] New Zealand Transport Agency (2015) Minimum standard for utility identification and protection on road projects. Retrieved from: https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Zero-harm/Utility-identification/ZHMS-03-Utility-Identification-and-Protection-on-Road-Projects-v1.2.pdf.

and equipment. This may enable site works to commence earlier and/or more efficiently.

Less expenditure on survey equipment

Wider availability of PPP is also anticipated to reduce the need for costly surveying equipment for mapping tasks where sub-metre to decimetre-level horizontal accuracy is sufficient. Assuming all asset positioning information is accurate, in the long-term there is potential to reduce (but likely not eliminate) the need for locating equipment such as GPR. There is also the potential to reduce the need for associated labour, which is often specialised and costly. Both efficiencies have the potential to generate significant cost savings for operators.

In summary, these anticipated benefits have been classed under benefit categories as per Table WU2[358].

Table WU2 – Water utilities sector benefit categorisation

Benefit	Benefit category	Quantitative?
Reduction in accidental strikes – direct benefits	Avoided capital expenditure	Yes
Reduction in accidental strikes – indirect benefits	Operating expenditure savings	Yes
Reduced delay in underground asset digging	Operating expenditure savings	No
Less expenditure on survey equipment	Operating expenditure savings	No

17.5 Positioning needs and current methods

Discussions with the sector reinforced that positioning accuracy requirements differ for each benefit and across sub-sectors. The purpose of this section is to detail the positioning needs for accurately locating underground assets, and current tools and processes used to undertake the task.

17.5.1 Reduction in accidental strikes (direct and indirect)

A reduction in accidental strikes of underground assets requires having reliable and accurate positioning information available to all users.

There are numerous guidelines related to the surveying of above ground assets and locating and surveying of underground assets[359]. Positioning requirements regarding sub-surface horizontal and vertical accuracy remain broadly consistent across these guidelines and are structured into quality levels, with ‘A’ assigned to the asset with the highest levels of positioning certainty and ‘D’ with the least.

As shown in Table WU3, positioning requirements range anywhere from 20 centimetres for Quality Level C, to five centimetres for Quality Level A[360]. Quality Level C calls for ± 20 centimetres horizontal accuracy for the mapping of assets.

Table WU3 – Positioning attributes for utilities

Utility attribute information shall include:		Quality level			
		A	B	C	D
1	Utility owner	✓	✓	✓	✓
2	Indication of the utility type	✓	✓	✓	✓
3	Indication of the utility status (in service or unknown)	✓	✗	✗	✗
4	Indication of the utility material	✓	✗	✗	✗
5	Indication of the utility size	✓	✗	✗	✗
6	Indication of the utility configuration	✓	✗	✗	✗
7	Indicative location of the visible and subsurface features of the utility	✓	✗	✗	✓

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[358] Colour coding in Table WU2 has been used to more clearly highlight the relevant benefit categories.

[359] For example, the New Zealand Utilities Advisory Group Code of Practice Act 2011 and Utilities Access Act 2010 in New Zealand and the Australian Standard AS5488 (Draft) for Sub Surface Utility Information in Australia. Retrieved from: https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Zero-harm/Utility-identification/ZHMS-03-Utility-Identification-and-Protection-on-Road-Projects-v1.2.pdf

[360] New Zealand Transport Agency (2015) Minimum standard for utility identification and protection on road projects. Retrieved from: https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Zero-harm/Utility-identification/ZHMS-03-Utility-Identification-and-Protection-on-Road-Projects-v1.2.pdf.

Utility attribute information shall include:		Quality level			
		A	B	C	D
8	Interpolation of the location and direction of the subsurface utility using visible features or GPS coordinates if available, as points of reference	✗	×	✓	✗
9	Feature codes of visible features including but not limited to pits, access chambers, poles, valves and hydrants	✓	✓	✓	✗
10	The location of visible features measured in terms of spatial positioning with a maximum horizontal tolerance of	50mm	100mm	200mm	N/A
11	Feature codes of visible and subsurface features including but not limited to pits, access chambers, poles, valves, hydrants	✓	✓	✓	✗
12	Subsurface feature vertical tolerance	50mm	100mm	N/A	N/A
13	Subsurface feature horizontal tolerance	50mm	100mm	200mm	N/A

Currently, there are two points where an underground asset can be mapped:

- When it is exposed (during construction or maintenance for example) or
- When it remains underground.

17.5.1.1 Exposed asset

Once an asset has been exposed or a location worked out from evidence at the surface, a dual-frequency GNSS receiver is then often used to record the horizontal and vertical position of the asset. This positioning information can either be obtained through the RTK position from a correction service or post-processed in the office. The data is then ready to be consumed by office processes and ingested into Computer-Aided Design programme (CAD), GIS, or directly into asset management software.

However, based on discussion with the sector, a key challenge in exposed asset mapping is the availability of qualified surveyors to undertake the mapping exercise while the asset is visible. It is not unusual for an asset to be physically covered up by the time a surveyor gets out on-site. In such instances, the surveyor often has to rely on the evidence left by trenching scars or other markers left by the contractors to guide their mapping exercise.

The trenching scars and markers are subject to horizontal inaccuracies, and do not give an accurate representation of the depth at which an asset may be located. Nevertheless, surveyors use this information to inform their mapping exercise, which is then translated onto as-built plans for future references. The inherent inaccuracies of as-built plans expose contractors or members of the public to the possibility of inadvertently striking an asset.

17.5.1.2 Underground asset

The sector currently utilises a combination of different technologies for the detection of underground assets. To determine the vertical position of an underground asset locator, use pipe and cable tracers, which utilise low-frequency electrical currents to induce signals from metallic assets, or transmitters[361]. Combining the tracer data with GPR provides a more thorough understanding of location and depth.

GPR is much better equipped to locate non-conductive underground assets. Where the pipe network can be accessed from the surface (for example storm water and sewer network) sonde equipment[362] is able to be inserted and its location and depth below the surface can be determined by EML tools from the surface.

When utilised correctly by experts, these technologies combined can provide more accurate horizontal and vertical positioning of the buried service. Once the buried service has been located and marked up, specialised GNSS survey equipment is required to survey the position and capture associated metadata. At present, this process requires highly skilled labour to operate, which presents the following challenges:

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[361] New Zealand Transport Agency (2015) Minimum standard for utility identification and protection on road projects. Retrieved from: https://www.nzta.govt.nz/assets/Highways-Information-Portal/Technical-disciplines/Zero-harm/Utility-identification/ZHMS-03-Utility-Identification-and-Protection-on-Road-Projects-v1.2.pdf.

[362] Devices for testing physical conditions (as at high altitudes, below the earth's surface, or inside the body). Retrieved from: https://www.merriam-webster.com/dictionary/sonde

Delays

Given the requirement of specialised locators to operate GPRs and pipe and cable tracers, there is often a strong demand backlog which results in delays for waiting projects. In certain instances, contractors may proceed without consulting locators to avoid significant project delays.

Cost

The sheer cost of equipment and associated labour means such methods described above are generally unavailable to the wider public, who often dig up sites without locating/validating services and only relying on publicly available information (such as 'Dial before you dig' hotlines).

Lack of availability and high costs result in contractors and members of the public digging up sites unaided by the accurate positioning information of underground assets, exposing them to the risk of accidental strikes.

Based on the positioning requirements outlined in Figure U4, the PPP signal is expected to be of most use to the utilities sector (including the water utilities sub-sector). PPP has the potential to provide decimetre Category C surveying capability to a wider array of people, effectively minimising the need for specialised labour and equipment. If a greater number of assets can be mapped whilst exposed, and a greater number of people can use this information to accurately ascertain where underground assets are, a reduction in accidental strikes can be anticipated in the long-term.

In addition, better understanding of underground assets can help streamline construction timelines, assist asset maintenance and monitoring, and help guide future residential or commercial development.

It is acknowledged that in certain instances, sub-decimetre positioning requirements will necessitate the need for existing specialised processes, where Quality Levels A to B are required. However, discussion with the sector suggests that PPP has the potential to bring large parts of existing utility networks up to Quality Level C standard. This is particularly relevant given the challenges associated with availability and the cost of specialised services as noted earlier, and presents a potential point of difference for the PPP signal.

17.5.2 Reduced delay in underground asset digging and less expenditure on survey equipment

More widespread and timely access to precise positioning means contractors and members of the public alike will be less dependent on specialised labour and equipment, thereby reducing potential delays and costs associated with digging operations.

Given the need to accurately locate underground assets in order to unlock these benefits, it is proposed that the positioning needs are the same as the prior benefit, which states a decimetre accuracy requirement for accurate mapping and detection of underground assets.

17.5.3 Sector benefits

The following sections detail the benefits of SBAS relative to the status quo, describe the anticipated economic impact, and estimate how benefits are attributed across the three signals.

It is important to reiterate that only economic benefits for the water utilities network have been contemplated in this analysis. However, it is expected that the scale and magnitude of these benefits in reality will be considerably higher than those presented.

17.5.4 Signal attribution

Given the decimetre level accuracy required by Quality Level C, PPP is considered the only signal suitable for mapping assets, and hence accrues 100 percent of the benefits outlined in Table WU4. L1 and DFMC are not expected to provide a level of accuracy that meets the performance expectations for the benefit categories explored.

Indicative test results have been provided by FrontierSI as representative results of the testing carried out by the Demonstrator Project in this sector. The testing was carried out in open sky to moderately obstructed environments with mid-range equipment. Values are presented at a 95 percent confidence interval.

Table WU4 – Water utilities sector signal attribution

Signal	Water utilities sector test results	
	Expected horizontal performance (m)	Expected vertical performance (m)
L1	-	-
DFMC	-	-
PPP	0.4	0.8

Benefit	Positioning needs	Signal attribution			Comment
		L1	DFMC	PPP	
Quantitative benefits					
Reduction in accidental strikes (direct and indirect benefits)	Decimetre	0%	0%	100%	Decimetre accuracy required to map asset
Qualitative benefits					
Reduced delay in underground asset digging	Decimetre	-	-	✓	Decimetre accuracy required to map asset, reducing need for specialised equipment
Less expenditure on survey equipment	Decimetre	-	-	✓	Decimetre accuracy required to map asset

17.5.5 Uptake rate

An S-curve uptake curve has been deployed for all benefits in the utilities sector. This reflects discussion with the sector which suggests slow initial uptake reflected by early adopters, followed by exponential uptake as the majority of the market follows suit, and a steady plateau in the long-run. This uptake rate will commence from the date that the SBAS PPP signal is assumed to be available (i.e. 2020).

Additionally, it is assumed that this uptake rate is also reflective of the complex set of undertakings that need to occur for the reduction in accidental strikes benefit to accrue. For example, all buried services would eventually need to be located and surveyed. This means that all existing data would need to be validated by a locator, assigned a quality level, and all bare land will need to be swept clear using locator tools.

This assessment manifests in a cap of 70 percent to the uptake rate based on a comment from the sector about how effective they expect the SBAS signals may be.

17.5.6 Quantitative benefits

17.5.6.1 Reduction in accidental strikes (direct)

Over a 30-year assessment period, it is anticipated that a total of 139,958 accidental strikes on the water utilities sub-sector will be avoided, resulting in direct cost savings of PV$18m to water network operators over a 30-year period.

Savings, in the context of this benefit, refer to a combination of avoided material costs and labour costs associated with the reparation of damaged assets. In simple terms, it captures the cost of a work crew heading out on-site to repair a pipe leak, plus the cost of materials.

To calculate savings, accidental strike data provided by a Demonstrator Project has been used to understand the average length of the network, per accidental strike. By applying this factor to the total Australian and New Zealand water network, a total number of strike estimate has been derived across the entire network over a 30-year period. This worked out to be approximately 1.76m accidental strikes.

Discussion with the sector suggested that democratisation of underground asset location data would likely assist in reducing accidental strikes across 70 percent of the network over a 30-year period.

A further discount was then applied to account for the fact that a greater understanding of an asset's location does not directly correlate to reduced strikes. A survey of members of the Australian Dial before you dig service reported that there is still a 22 percent likelihood of an accidental strike to utility networks even if someone calls first for advice[363]. This proportion is likely to be a conservative estimate given that it accounts primarily for the general population. Experienced asset manager and contractors would be

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[363] Dial before you dig (2018) Newsletter. Issue 41. Retrieved from: https://www.1100.com.au/wp-content/uploads/2018/12/DBYD-News-Issue-41.pdf

expected to be more effective in interpreting information about the spatial location of a given utility.

Finally, a PPP attribution factor was then applied in recognition of the fact that PPP is one component of many inputs that will go into democratisation of underground asset information such as the hardware and software necessary to undertake PPP-enabled surveying. This was assumed to be 33 percent based on a view that there are three core components (positioning technology, surveying applications and mobile phone technology).

The anticipated total number of accidental strikes avoided by utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table WU5. As noted earlier, this uptake rate has been capped at 70 percent over 30 years in recognition of the complex set of undertakings that need to occur for the reduction in accidental strikes benefit to accrue.

Table WU5 – Reduction in accidental strikes direct cost savings (30-year calculation)

Factor	Value	Notes
Kilometre (km) of network per accidental strike	10km per strike	Total water utilities sub sector network length divided by average annual strikes
Total water utilities sub sector network length	18m km	Summation of AUS and NZ water network length[364]
Total number of accidental strikes	1.8m	Total water network length divided by 10km per strike rate
Total accidental strikes applicable to 'democratisation of data' concept	1.2m	70% of strikes avoided based on sector advice
Discount owing to effective action based on availability of information	960,000	22% likelihood of accidental strikes occurring even with better information
Total accidental strikes avoided attributable to PPP	317,000	33% of avoided strikes attributable to PPP
Adjusted for uptake	140,000	S-curve over 30 years
Gross value	$63m	Based on an average direct cost of repair provided by an affiliate to the Demonstrator Project
Present value	$18m	Discounted at 6.5%

Note: Totals may not sum due to rounding

17.5.6.2 Reduction in accidental strikes (indirect)

Over a 30-year assessment period, it is anticipated that a total of 139,958 accidental strikes on the water utilities sub-sector will be avoided, resulting in indirect cost savings to the wider economy of PV$259m over a 30-year period.

This calculation follows the same methodology as that for the reduction in accidental strikes to utilities (direct) benefit category but has one main replacement value regarding the indirect costs.

The fundamental premise of this benefit is that there are flow-on implications from the water utilities' network outages. For example, restaurants may not have access to potable water which means they may be forced to shut down their business for a short time, or storm water overruns close down roads causing traffic congestion.

A recent research report by the University of Birmingham[365] attempted to quantify these flow-on costs to the wider economy in the United Kingdom based on 16 real-world case studies.

The underpinning valuation methodology of this study considered economic, health and social costs. It found that:

- True indirect costs had a ratio of 3.7:1 – these primarily relate to downstream economic effects such as reduced income for users of the water utilities network.
- Social cost had a ratio of 25:1 – these are much broader and consider flow-on implications to the health sector and wider externalities such as environmental impacts.

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[364] Please note that this figure has been derived for analytical purposes and represents a sum of the Australian and New Zealand networks over a 30-year period (i.e. network length x 30). This has been done as the likelihood of a strike has been assumed as constant each year.

[365] Makana, L; Metje, N; Jefferson, I; Rogers, C (2016) What do utility strikes really cost? University of Birmingham, School of Engineering.

- A sum of indirect and social costs resulted in a ratio of 29:1.

For the purposes of this assessment, it is assumed that not all social costs would come to fruition – such as health sector costs and reduced quality of life – given that these costs are based on an assessment of all utilities. Moreover, while these are important concepts, the valuation methodology for these assessments becomes more speculative the more distant the link between the direct cost and the indirect cost. Accordingly, an average of the indirect and social costs has been utilised in the analysis – or 14:1.

The anticipated total number of accidental strikes avoided by utilisation of the SBAS signals has then been adjusted for uptake and discounted to present values to arrive at the final economic saving shown in Table WU6.

Table WU6 – Reduction in accidental strikes indirect cost savings (30-year calculation)

Factor	Value	Notes
Kilometre of network per accidental strike	10km per strike	Total water utilities sub sector network length divided by average annual strikes
Total water utilities sub sector network length	18m kilometres	Summation of AUS and NZ water network length[366]
Total number of accidental strikes	1.8m	Total water network length divided by 10km per strike rate
Total accidental strikes applicable to 'democratisation of data' concept	1.2m	70% of strikes avoided based on sector advice
Discount owing to effective action based on availability of information	960,000	22% likelihood of accidental strikes occurring even with better information
Total accidental strikes avoided attributable to PPP	317,000	33% of avoided strikes attributable to PPP
Adjusted for uptake	140,000	S-curve over 30 years
Gross value	$915m	Based on an average indirect costs of strike events of 14:1
Present value	$259m	Discounted at 6.5%

Note: Totals may not sum due to rounding

17.5.7 Qualitative benefits

17.5.7.1 Reduced delay in underground asset digging

An added benefit of enabling faster surveying of underground assets means there is potential for a reduction in delays associated with either digging up assets or covering assets. These delays can have significant downstream impacts on other phases of the construction/maintenance lifecycle which can come at a significant cost to the network operator. A one-day delay due to surveyor unavailability, for example, also means construction workers, planners, architects, project managements, engineers, all must be retained for an additional day.

For example, assume a 100-lot residential development, at a cost of $500,000 each, has a weighted average cost of capital of 8.4 percent, based on an 80/20 debit to equity ratio. A single day of delay amounts to approximately $80,800 in costs. This cost reflects the cost of borrowing for one day, but more importantly it represents the opportunity cost of not being able to use the funds elsewhere for more productive tasks. Therefore, reducing delays helps to improve the overall productivity of not only the sector, but the overall economy.

17.5.7.2 Less expenditure on survey equipment

For those surveying tasks which do not require centimetre positioning accuracy, PPP has the potential to reduce the need for specialised, and costly, surveying equipment and labour.

For exposed assets, PPP could enable operators to avoid correction service subscription costs, which can range anywhere from $1,000 to $5,000 per annum. In a future state, once all buried services have been located and validated, improved accuracy and integrity of as-built drawings along with greater availability may also reduce the need for costly GPR systems. These systems can cost operators anywhere between $20,000 and $80,000, or

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[366] Please note that this figure has been derived for analytical purposes and represents a sum of the Australian and New Zealand networks over a 30-year period (i.e. network length x 30). This has been done as the likelihood of a strike has been assumed as constant each year.

between $1,400 and $3,000 a day if GPR surveyors are hired, depending on the complexity of a given task[367].

Even if a small portion of existing jobs can avoid standalone GNSS correction service subscription costs, this could amount to significant operational savings for operators. Unfortunately, discussion with the sector has failed to highlight the proportion of jobs which currently use such systems, and as such, it is difficult to establish the size of these potential operational savings.

17.6 Summary

Table WU7 contains a summary of benefits, their positioning needs, and the status quo with regards to positioning. The quantifiable economic impact of PPP in the water utilities sub-sector is anticipated to be **PV AUD $277m** over 30 years.

Table WU7 – Benefits summary (30-year, NPV, AUD)

Benefit	Positioning needs	Status quo	Anticipated benefits over 30 years	Signal attribution
Reduction in accidental strikes direct benefits and indirect benefits	Decimetre	Combination of manual processes and costly and specialised equipment/ labour	140,000 accidental strikes avoided at a saving of $18m for operators and $259m for downstream parties	PPP
Reduced delay in underground asset digging	Decimetre	Strong reliance on costly and sparse specialist equipment and labour	Reduced labour costs and overall project costs	PPP
Less expenditure on survey equipment	Decimetre	Strong reliance on costly and sparse specialist equipment and labour	Reduced labour costs and overall project costs	PPP

A range of additional applications in the utilities sector have been identified throughout this research but have not been quantified (or described qualitatively) for a range of reasons[368]. A collection of these applications is provided in the additional applications Chapter 18.

17.7 Assumptions and limitations

The economic modelling undertaken for this Chapter has been based on a combination of official data sources, desktop research, information provided by the Demonstrator Project, as well as the use of rational and logical assumptions. These assumptions have all been agreed in discussion with the relevant Demonstrator Project(s) and FrontierSI.

In addition to standard caveats around economic modelling, the following assumptions and limitations are worth highlighting:

Utility sector coverage

Limitations in the provision of data has necessitated a focus on just the water utilities sector. However, it is expected that the general trajectory of these benefits would apply to all other utility sub-sectors to greater or lesser degrees.

Accidental strike rate

Strike rates have been taken from data provided by a large regional town centre. It is assumed that the same strike rate holds true for the entirety of the water utilities sub-sector across Australia and New Zealand. This is predicted to be conservative, as high-density metropolitan areas like Auckland, Melbourne, and Sydney are likely to have a higher accidental strike rate.

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[367] https://clu-in.org/characterization/technologies/gpr.cfm

[368] Reasons include lack of sufficient evidence to quantify or qualitatively describe benefits; lack of confidence that the SBAS signals can materially assist; or being nascent in the innovation cycle.

Probability of accidental strikes

It is assumed that the accidental strike rate employed will be maintained over a 30-year period. It is acknowledged, however, that the progression of technological innovations may reduce this probability, and/or the continued densification of communities may increase this probability.

Accidental strike cost

Data provided fails to detail the cost profile of accidental strikes. For the purpose of this analysis, it has been assumed that actual spend data is reflective of labour plus capital costs associated with the reparation of damaged assets.

PPP uptake rate

Assumed to be S-curve uptake to a 70 percent over the 30-year forecast period.

Present value discount

All quantitative benefits have been discounted at 6.5 percent, representing the mid-point value of the New Zealand Treasury and Infrastructure Australia recommended discount rates for infrastructure. This is also the mid-point between New Zealand Treasury discount rates for technology and infrastructure investments.

Indirect cost multipliers

The research relied on for the indirect cost multiplier incorporates indirect economic consequences as well as much broader conceptions of impacts to the health system and externality effects on the environment. An average of the indirect costs and health/social costs has been employed for this assessment.

18. Additional applications

The purpose of this Chapter is to outline a range of potential applications where the SBAS signals could be used for the benefit of the Australian and New Zealand economies both now and 30 years in the future. These applications are all additional to those described in the other sector Chapters.

The starting premise for this entire body of work is that the SBAS signals have the potential to positively and fundamentally change the composition of the economy and the use of positioning technology in all facets of life.

The sector Chapters explicitly highlight the potential benefits that could be expected to accrue from the activities of the 27 Demonstrator Projects and their respective sectors. Importantly, these Demonstrator Projects and sectors have been selected with a view to capturing benefits from the SBAS signals where it can reasonably be expected they would accrue, based on prior studies and an understanding of an operational SBAS in relation to the present-day economy.

However, there will be a range of benefits that could accrue to other applications that are either already known but have not been included as part of this study, through to unknown applications that may materialise in the future. Predicting the scale and nature of these unknown impacts over a 30-year period is not possible. An analogy frequently used throughout this Demonstrator Trial is that to understand the true impacts of the SBAS signals would be similar to attempting to identify all the benefits of the internet upon its inception.

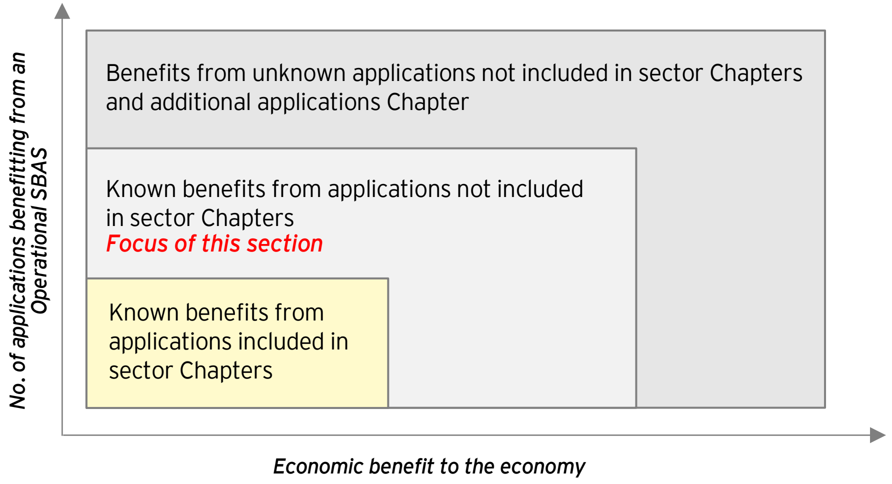
While benefits from unknown applications cannot possibly be presented with any confidence by definition, the Demonstrator Project shortlisting process, along with discussions with Demonstrator Projects themselves, have shed light on some of the present day and future applications that the SBAS signals can enable, but have not been explicitly captured in the sector Chapters.

These applications are split into two types:

- Applications captured in each sector Chapter, but which can apply in other sectors.
- Applications discovered through discussions with the Demonstrator Projects and sector participants, as well as those applications identified through the Demonstrator Project shortlisting process.

A conceptual depiction of the breadth of these benefits is provided in Figure 16. The remainder of this Chapter discusses these applications to show the potential upside that exists through the deployment of an operational SBAS.

Figure 16 – Conceptual depiction of ability to capture additional applications



It is important to note that no level of formal validation or assessment of likelihood or timing of implementation has been provided throughout this section. In this sense, the following sections represent a spectrum of possibility rather than an assessment of benefit (like the sector Chapters).

It is also important to note that referencing of all applications has not been undertaken in every instance, because of breadth of conversations that have underpinned the identification of these applications. Where a clear and obvious reference for an application is possible it has been made.

18.1 Agriculture

Benefit	Description
Known benefits captured in analysis but applicable elsewhere	
Reduction in crop lost to disease	Enhanced UAV disease detection due to SBAS signals has the potential to extend beyond horticulture and can also be deployed in the forestry and broadacre sectors. Furthermore, high-quality positioning has the potential to better geo-tag weeds, meaning that they can be destroyed before they spread and infect wider crop areas.
Efficient pasture utilisation with virtual fencing	The benefits of virtual fencing in this analysis have been limited to dairy farms; however, it is acknowledged that other livestock farms which incorporate grazing, such as beef and sheep farms, may also stand to gain productivity improvements.
Reduced livestock loss via enhanced animal tracking	The tracking of sheep to detect predation events or illness has the potential to be applicable in other livestock farms, where animals are large enough to be fitted with GNSS trackers. Examples of such animals could be alpacas or goats.
Enhanced health and safety	SBAS-enabled trackers, or even augmentation of the positioning capability of smart phones, has the potential to make it easier and quicker to identify and respond to workers who may be hurt in isolated areas. This scenario may exist in many sectors outside the broadacre sector, such as forestry workers, and sheep and beef farmers.
Known benefits not captured in analysis	
Enhanced livestock breeding management	Enhanced livestock tracking enabled by the SBAS signals has the potential to improve breeding management through more accurate identification of cow-calve pairings. This is anticipated to enable farmers to accurately trace the lineage and reproduction of high-quality genes, helping to enhance profit margins. Furthermore, cows become more active when ready for insemination and enhanced positioning can provide farmers with a better understanding of when a cow has been inseminated (i.e. when a geo-tagged cow and bull come within a certain proximity or a certain duration). This benefit is also applicable to other forms of livestock.
Remote virtual fencing	The wide coverage of SBAS signals has the potential to enable remote herding via remote virtual fencing, which can help farmers react quicker during emergency events (such as natural disasters) and minimise potential stock loss. This benefit is also applicable to other forms of livestock.
Reduction in livestock loss to at-risk birthing	At-risk birthing locations are a material problem within the livestock sector and can occur when animals birth offspring in locations which may place them in immediate risk of harm, such as sheep giving birth to lamb on a steep mountainside. Enhanced tracking of livestock can help farmers proactively manage instances of at-risk birthing.
Nutrient tracking on farms	Livestock are major conduits for nutrient transfer around farms. According to discussions in the sector, enhanced tracking of livestock can provide a better understanding of nutrient flow around a farm, which in turn can provide real-time understanding of nutrient build ups and inform management practices. Tracking livestock can also help farmers understand if livestock are entering waterways which may support regulatory compliance.
Enhanced landscape mapping	Discussion with the sector, highlighted the potential for enhanced landscape mapping in remote and rural farms, which in turn would assist with identification of environmentally sensitive areas, and assist tactical planning for farming operators.
Plant breeding cost savings	The SBAS signals have the potential to deliver significant savings in costs associated with large scale plant breeding. More specifically, the use of SBAS signals could enable inter-row seeding and denser planting structures that could unlock breeding and genetic benefits. More efficient use of land could also lead to savings associated with less staff for in-field measurement and manual data collection would be further enhanced by the potential for more accurate data.
Reduction in chemical run off on farms	The SBAS signals have the potential to reduce runoff from farms into surrounding waterways, through the more efficient application of chemicals and fertilisers in particular. A reduction in overlaps is anticipated to reduce the total volume of inputs used, which in turn reduces the volume of runoff.

Benefit	Description
Efficient pest-management	Predator control is an on-going activity in which targeted pest species (such as possums in New Zealand) are killed, typically through kill traps and/or toxin applications. When predator control is performed in native forest, it is either by aerial application or by physically walking through the forest, maintaining traps and/or distributing toxic baits. The latter requires an infrastructure presence that may include cleared tracks, bait stations, and/or pest monitoring devices. Infrastructure of this type can be in place for up to 20 years. They are all, however, positioned using either standalone GNSS or manual maps, which naturally gives rise to positioning errors, sometimes up to 30 metres horizontally in under-canopy environments. This can result in time-consuming and costly delays when devices need to be found and/or relocated. Accurate SBAS-enabled trackers have the potential to guide workers to devices more quickly, reducing the time and effort required which driving operational efficiency. In addition, the geo-referencing of devices could unlock rich data, which could then be used for pest-management purposes.

Environmental management via enhanced geo-fencing

The agriculture sector is constantly seeking ways to reduce or mitigate the potential impact of farming operations on the surrounding physical and natural environment, especially in sensitive areas such as waterways. A prominent example of an adverse impact is nutrient runoff from farms (biomass chemical leachate from faeces, or farming chemicals such as fertilisers, pesticides, and herbicides). Another example is in the form of livestock traversing waterways, which can lead to direct nutrient/chemical deposits into waterways, and sedimentation as livestock traverse the waterbed. Whilst farms have deployed measures, such as fences, to mitigate and reduce the risk of adverse effects, the use of SBAS signal-enabled geo-fencing potentially offers a cheaper, more robust alternative to physical measures. This can encourage uptake within the sector, helping to reduce overall environmental impacts, but also allowing the sector to empirically validate the environmental credentials of their farming operations. This validation exercise might also be a useful data input for monitoring purposes – potentially reducing the administrative burden on administrative agencies.

18.2 Aviation

Benefit	Description
Known benefits not captured in analysis	
Divestment of ILS	ILS is defined as a precision runway approach aid based on two radio beams which together provide pilots with both vertical and horizontal guidance during an approach to land. Deployment of an operational SBAS has potential to serve as a substitute to ILS in the long-term, which may reduce the need to renew existing ILS or invest in new ILS. This can help support significant capital and operational savings for airport operators.
Reduction in aviation-related carbon emissions	Deployment of the SBAS signals in the aviation sector is anticipated to reduce the likelihood of weather-related flight diversions and delays, along with the associated costs to reset the network. In addition to the direct operational savings for airline operators, and the indirect savings to economic productivity, there is also the material benefit of reduced emissions discharged due to a reduction in the total number of flights per annum.
Adoption of flying taxis	There are a range of parties currently exploring the development potential for flying taxis. Examples of this include Kittyhawk, Uber, and Boeing. In a similar way to the use of positioning technology to support UAV and automated and connected vehicle uptake, it is expected that the SBAS signals could support the uptake of flying taxis. Moreover, the use of SBAS signals could also support the creation of airspace design using geo-fences.

UAV parcel delivery

The likes of Amazon, Boeing and Google are currently in the process of exploring and establishing their own traffic control networks for low-level altitude UAV travel in a bid to enable UAV parcel delivery systems. While the use of automated cellular and web applications is being touted as ways to manage the risk of collisions and to assist navigation of deliveries, the deployment of high-precision positioning capability over a large coverage area in the form of the SBAS signals could also serve as a key enabler. Note that the integrity provided by SBAS signals will likely aid/enable regulation changes required for this to become commonplace. Deployment of an operational SBAS would help Oceania to adopt any overseas technologies requiring the SBAS signals, and potentially lower the barrier for UAV parcel delivery systems in Australia and New Zealand. In addition to improving the efficiency and convenience of purchasing goods, the introduction of UAV parcel delivery systems could unlock a variety of jobs and industries for the Australian and New Zealand economies.

18.3 Construction

Benefit	Description
Known benefits captured in analysis but applicable elsewhere	
Reduction of falls from height incidents	The focus of this analysis has been on the geo-fencing of hazards on construction sites to prevent falls from height incidents; however, it is noted that such geo-fencing has the potential to reduce other types of injuries too such as trips, or collisions with moving objects. With a strong focus on zero harm within the sector, the potential to reduce all causes of harm on-site is viewed as a significant benefit, which stands to enhance the productivity of the construction sector.
Geo-fencing of hazardous areas on-site	It is conceivable that geo-fencing of hazardous activities can also be employed across a range of other economic sectors, for example the transport sector (including maritime and rail), the warehousing and logistics sector, or the manufacturing sector.
Improved collision avoidance systems in construction vehicles	The focus of this sectoral analysis was the improvement of CAS in construction vehicles. Currently there are large buffer zones in CAS that lead to frequent false positives, to the point that the users often lack trust in the system and turn it off. This increases their susceptibility to collisions leading to serious injuries or fatalities. SBAS signals are anticipated to provide greater accuracy and spatial resolution therefore reducing the buffer zones and false positives. This can increase confidence in a vehicle's CAS, resulting in a reduction in harm to people and damage to vehicles caused by collisions.
Known benefits not captured in analysis	
Workflow management	Discussion with the sector suggests the wide availability of precise positioning via the SBAS signals has the potential to make the management of workers and plant on-site more efficient, which in turn has the potential to greatly improve workflow management. Better positioning awareness of resources is anticipated to assist the prioritisation and management of tasks, which can then help optimise routing and allocation of resources to drive time savings and overall operational productivity.
Efficient construction surveying	Deployment of an operational SBAS has the potential to reduce the need for costly surveyors during the enabling works stage of construction. By providing building surveyors (different to quantity surveyors and with a focus on resource allocation) and site planners with decimetre-level site characteristic maps without the need for specialist labour and equipment, certain survey activities could potentially be undertaken quickly and at a lower cost to drive operational productivity.
Smart construction	Smart construction is an increasingly utilised concept which involves leveraging technological innovations for the construction industry. This concept can involve UAV site surveying to create 3D models of construction sites. Smart construction covers critical steps in a project's development, from initial site survey and design, through to machine control management, device interconnectivity and review of project progress during the construction phase, and finally the development of detailed as-built information for future building and infrastructure maintenance[369]. These activities can drive significant operational productivity on-site (with Komatsu reporting a 230 percent improvement in operational productivity). The SBAS signals could provide redundancy for existing smart construction operations.
Monitoring of crane movements	More granular positioning information provided by the SBAS signals has the potential to enable better tracking of crane movement, specifically 'swaying' in high winds, which may pose health and safety risks to on-site and off-site personnel. It is feasible that alerts could be issued to operators to evacuate in cases where tracking of crane movements in real-time breaches defined thresholds (of crane movement).

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[369] Barry, R. (2017) Komatsu unveils new smart construction concept. Retrieved from: http://transporttalk.co.nz/news/komatsu-unveils-smart-construction-concept

Enhanced machine guidance

Machine guidance, through pre-programming of mapping data, removes the need for on-the-ground survey set out and string lining by construction crews, which means there are fewer opportunities for potentially dangerous interactions between machines and ground workers. This has the direct benefits of both reducing labour costs and improving health and safety outcomes. In addition, enhanced machine guidance can lead to a reduction in double handling of materials, time-saving efficiencies, reduced wear and tear on machines, and improved utilisation. Currently, enhanced machine guidance is achieved using a combination of standalone GNSS augmented with inertial sensors. The deployment of an operational SBAS could afford contractors with similar levels of accuracy without the need for expensive sensors. This in turn could improve the uptake of enhanced machine guidance within the sector and the prevalence of benefits noted above, all of which would help improve the safety and operational productivity of the construction sector.

18.4 Consumer

Benefit	Description
Known benefits captured in analysis but applicable elsewhere	
Automated delivery robots used for other civic duties	Last mile delivery (LMD) describes the transport of goods between the supplier and consumer as fast as possible to meet consumer needs. It is anticipated that improvements in the positioning performance of automated robots using the SBAS signals will improve their reliability and ease of use. In addition to performing their core duties, LMDs can also record real-time inspections of pavement condition, undertake policing activities, and even pavement cleaning. By promoting the greater uptake of LMDs, these wider civic benefits may also materialise.
Known benefits not captured in analysis	
Enhanced tracking of people for a range of public-good activities	In isolated circumstances, enhanced utilisation of the SBAS signals could applied to the geo-locating of smart phones and, by extension, people. This could then be applied to people in search and rescue operations, tracking of emergency services personnel in disaster situations, as well as individuals with illnesses who may need to have specific assistance at the onset of a change in their health status. In some instances, this activity is already being undertaken through standalone GNSS. In these instances, the SBAS signals may enable more accurate tracking, including in a wider range of environments.
Improved smartphone application effectiveness	Discussions with positioning experts suggest that many smart phones in today's market utilise standalone GNSS yet remain SBAS-capable. The deployment of an operational SBAS is anticipated to improve the positioning information afforded to current and future smart phones, which in turn could improve the effectiveness of position-based navigation apps, ride-share apps such as Uber, or social apps.
Elite sports trackers	GPS/GNSS trackers are used to track elite sportspeople and provide vital telemetric information for performance purposes. The greater accuracy offered by SBAS signals could allow better behavioural/movement information to better inform the athletes/teams.

Enhanced tracking of electronic monitors

New Zealand's use of electronic monitors for prisoners and at-risk individuals is extensive and represents one of the highest deployment rates in the world. Uncertainty with respect to the precise location of electronic monitors can sometimes lead to inefficient call-outs on behalf of Corrections Officers and the Police, all of which comes at a cost to government. Moreover, standalone GNSS trackers on monitors require mobile coverage, which are subject to blackspots. This means that in certain instances, individuals are housed in second or third choice locations, away from social support groups such as family, which can negatively impact on rehabilitation and detract from the government's desired outcomes. An operational SBAS can improve the performance of electronic monitors and can reduce the likelihood of false positives in the tracking of individuals. These can help reduce the likelihood of misconduct and violations, whilst also improving the feasibility of a wider range of housing options, which could prove less costly and lead to better social outcomes.

18.5 Maritime

Benefit	Description
Known benefits captured in analysis but applicable elsewhere	
Port management - logistics management	Port planning benefits anticipated by the SBAS signals are also anticipated to be applicable in the wider world of logistics, especially in distribution centre environments. The SBAS signals can serve as a primary or backup system for optimal route planning of forklifts and straddle carriers, and could also be used as part of automated package handling systems in the future.
Known benefits not captured in analysis[370]	
Provision of positioning signal in coastal waters	In New Zealand there is currently no directly comparable DGPS system as there is in Australia. This means that the benefits of a DGPS system (as noted in the Maritime sector sub-Chapter) are not being realised in New Zealand waters. The SBAS signals offer a greater number of mariners the potential to access accurate positioning information, which can enable safer and more efficient navigation in coastal waters.
Uptake of unmanned surface vessels	Unmanned surface vessels are increasingly utilised in a range of maritime applications including oceanography, military applications, and hydrographic surveys. Where relevant, it is possible that SBAS (through the integrity portion of the message) may aid with regulation changes, which could facilitate greater uptake and adoption of these vessels.
More efficient navigation charting	Discussion with the sector suggests that there remains potential for the improved absolute positioning afforded by SBAS signals to expedite the hydrographic surveying and charting of new navigation routes within the cruise sector. This means new routes could be brought to market faster, leading to improved revenue realisation potential.
Marine mammal tracking	Radio frequency identification (RFID) is a wireless tracking system to transfer data. Discussion with the research sector suggests that SBAS could provide a superior solution to RFID in applications such as marine mammal tracking.
Post-disaster marine surveying	The SBAS signals could be utilised for post-earthquake surveying. For example, after New Zealand's last major earthquake in November 2016, a wharf moved by 70 centimetres after the earthquake. The SBAS signals could establish the new position immediately.
Coastal erosion surveying	The SBAS signals could be utilised to map coastal erosion in real-time, replacing existing DGPS and RTK systems used for such purposes, which come at a cost to port authorities.

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[370] Many of these benefits are based on content from the MIAL Demonstrator Project.

Benefit	Description
Removal of military debris	Broad coverage area of SBAS signals could assist in the removal of military debris in remote marine locations as it would help identify the exact location and ensure destruction. This could generate labour time and operating expenditure savings for the defence sector.

Automated shipping

A ship's ability to monitor its own health, establish and communicate what is around it and make decisions based on that information is vital to the development of automated operations. Navigation and collision avoidance will be particularly important for remote and automated ships, allowing them to successfully navigate open-sea and in-port environments efficiently and safely. Discussion with the sector suggests that the SBAS signals may have a role to play in any future development of automated ships, due to the signals' ability to provide high-precision and continuous absolute positioning over a large coverage area. Direct benefits associated with automated shipping include more efficient use of space in ship designs (through reduced design parameters related to the accommodation of people), more efficient use of labour, fuel, and other operational inputs, enhanced safety outcomes for ship crew (or lack thereof), and more efficient navigation leading to travel time savings. Indirect benefits often revolve around the creation of new industries within the economy, faster delivery times of exports and imports, and enhanced capacity within existing ports.

18.6 Rail

Benefit	Description
Known benefits captured in analysis but applicable elsewhere	
Geo-referencing of network defects	Accurate geo-referencing of network defects is viewed as a significant benefit within the rail sector and is noted in the rail Chapter. Discussions with the sector have also noted the potential for such applications to be extended to rail yards and maintenance areas for pavement defect detection. Sector participants noted that rail yard pavements are often subject to heavy loadings from trucks and containers, which can lead to distressed pavements and eventually defects. In addition to posing potential safety risks, these defects can sometimes extend into significant faults requiring major rehabilitation. It is suggested that enablement of accurate, easy, and cost-effective geo-referencing via use of the SBAS signals could assist employees to record defects as they arise, and to allow operators to proactively manage and mitigate against further damage and cost (preventative maintenance). Accurate geo-referencing of rail network defects is also an important concept that could be applied in the resource sector. A significant amount of raw material (coal, iron ore etc) is often railed from mine site to port and these rail lines will experience wear and tear in a similar way to other freight and metro rail lines. Being able to more accurately geo-tag and identify defects could benefit the sector from an operational perspective (reduced time on-site for maintenance crews) and from a back-office perspective (reduced maintenance planning activity).
Known benefits not captured in analysis	
Deferred capital investment via improved headways	The analysis in this report has focussed on the potential for reduced headways within existing networks via the enablement of GNSS-based signal systems. In addition to operational savings tied to the divestment of existing terrestrial signal infrastructure, another key benefit raised by the sector has been the potential for deferred capital investment in the rail network due to more efficient utilisation. In simple terms, a reduction in headways is anticipated to unlock additional capacity on existing rail networks, prolonging the life of existing infrastructure and delaying the need for future expansions. It is noted, however, that this may be somewhat counterbalanced by an increase in operating expenditure due to heavier usage of existing infrastructure.

Benefit	Description
Communication between train and train controllers	GNSS information is currently communicated between train controllers and trains to understand the position of rail infrastructure (above ground/outdoors). This is a critical component of managing the network and is used for scheduling and emergency location. Better understanding of locomotives and wagon locations can enable better management of the system. Additionally, different locomotives and wagons can sometimes have different positioning systems which can lead to discrepancies in managing the system. For example, because there are different levels of positioning performance and systems used, it means it can be difficult to note which track they are on.
Reduced health and safety risk	Health and safety within the rail sector is an ongoing priority and many emerging technologies are being trialled within the market to explore ways of reducing the risk of harm on the network. An isolated, but potential, risk noted in the sector is for contractors who are sometimes unfamiliar with the rail network and who incorrectly identify their position on the network to rail planners and the operation centre. This typically manifests in rail planners being cautious about how locomotives can pass through affected areas. This can cause unnecessary network delays. Accurate positioning of contractor crews reduces the need for manual conveyance of positioning and can be conveyed to planners and conductors in real time to reduce the risk of accidents and delays.
Enabler of system integration	L1 and DFMC could enable an amalgamation of entire state/country rail signals into one system (in Melbourne this could result in an integration of system harmonisations between urban, rural trains, Yarra trams, and buses). It is possible that system integration could have safety benefits (i.e. interface with level crossings) and could also have network efficiency benefits for customers (better real-time knowledge of where units are). System integration is a common objective in overseas jurisdictions and has been progressed extensively in Europe through the European Rail Traffic Management System (ERTMS). The ERTMS aims to provide a new generation of train control and signalling capabilities in the European Train Control System which includes automatic train protection by continuously supervising train speed and braking.

Reduced risk of incorrect locomotive-trolley links

Rail networks consist of distribution depots, where locomotives deposit or collect trolleys containing freight. These depots often have numerous tracks flowing into them from the different lines within a network. Many tracks in such close proximity makes it difficult to locate trolleys using standalone GNSS. A locomotive relying on standalone GNSS positioning coordinates to pick up Trolley A may be at risk of accidently picking up Trolley B, which leads to flow-on operating expenditure tied to mis-delivery and the need to return the incorrect trolley and pick up the correct one. Use of SBAS signals and the improved accuracy they afford is anticipated to reduce such risks, thereby improving overall operational productivity.

18.7 Resources

Benefit	Description
Known benefits captured in analysis but applicable elsewhere	
Enhanced machine guidance	Similar to the construction sector, a potential application of the SBAS signals could be the enablement of machine guidance systems at a lower cost and across a wider geographical area. This in turn could enhance overall operational productivity by improving the efficiency of labour and plant on-site.
Known benefits not captured in analysis	

Benefit	Description
Augmented reality management	Provision of enhanced positioning information using the SBAS signals is anticipated to serve as a potential enabler of emerging technologies such as augmented reality technology within the resources sector. Potential applications of such technology could include real-time telemetry of plant on-site and real-time workflow management.
Improved health and safety via worker tracking	The expansive nature of mines within Australia specifically means that workers can often be working in remote areas away from most of the workforce. In such instances, accurate and timely positioning information becomes increasingly important in the event of an accident which requires urgent assistance. The coverage afforded by a system using the SBAS signals has the potential to provide precise positioning information of crews out in remote areas in real-time, ensuring assistance can be provided in a timely and efficient manner.

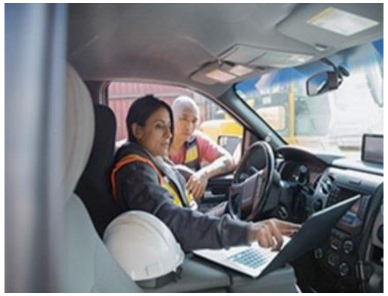
Automated haul trucks

Collectively referred to as advanced driver assistance systems, this automation technology of haul trucks in the resources sector ranges from simple to very complex. It includes the basic tools, like power steering, cruise control, automated gear changing, and anti-lock brake systems, but can also have more complex technology such as electronic stability control, which improves the trucks stability by actively assessing road conditions and adjusting vehicle handling to avoid the risks of skidding and rollovers. Automated trucks are anticipated to provide health and safety benefits by reducing the exposure of workers to safety hazards, helping the sector overcome potential driver shortages, and reducing operating expenditure such as fuel consumption (as driving is optimised for acceleration and braking). Current automated haul truck systems utilise a ‘fixed-block setting’ whereby trucks must wait for the truck ahead to clear a stretch of road, or ‘block’, prior to entering it. Provision of high accuracy and continuous positioning information in the form of the SBAS signals means trucks could be tracked in real time, potentially doing away with fixed blocks, and transitioning the system towards a moving-block setting where vehicles can move freely subject to keeping a minimum real-time distance.

18.8 Road

Benefit	Description
Known benefits captured in analysis but applicable elsewhere	
Provision of self-healing maps	Using self-healing road maps across other sectors, such as the resource or agriculture sectors, may enable vehicles to navigate environments autonomously in the future. An example of this would be automated haul trucks in mines, which could potentially use a combination of 3D maps and SBAS signal-enabled GNSS to navigate the environment in real-time.
Collision avoidance systems focussed on pedestrians and cyclists	While the focus of the road Chapter analysis has been on vehicle-to-vehicle collision avoidance systems, it is noted that there remains an emerging market for pedestrian and/or cyclist-oriented collision avoidance systems. These systems assist vehicle drivers avoid oncoming pedestrians or cyclists, through a combination of forward collision warning systems, automated braking systems, and hazard advisory systems. Absolute positioning remains important for the operation of such CAS, and as such, SBAS signals may serve as an enabler of this technology.
Smart parking via eRUC systems	Increased uptake of eRUC systems, as a result of a lower cost barrier by SBAS signals, may provide government with an effective stepping stone towards smart parking, whereby eRUC systems can effectively convey when and how long vehicles remain in parking bays, which can translate to accurate charges. This could lower the administrative cost burden on government agencies, whilst providing a rich source of data around parking utilisation that could inform urban planning.

Benefit	Description
Known benefits not captured in analysis	
Logistics and fleet management	Positioning technology has been implemented amongst many applications to facilitate, manage, and forecast the movement of freight, bulk materials handling, and haulage within the logistics sub-sector. The ability to provide and integrate higher-level positioning information (at the where-in-lane level) using the SBAS signals as part of logistics management systems is anticipated to facilitate more effective operations. More specifically, ACIL Allen's 2013 report *Precise positioning in the road transport sector* anticipates reduced fuel consumption, improved driver productivity through enhanced routing and navigation, and real-time driver performance to manage fatigue or other health risks. Furthermore, ride-share systems, which often rely on similar fleet data requirements may also stand to benefit from SBAS signals. For example, they may provide users with a more accurate understanding of where fleet vehicles are or in the case of ride-sharing, exactly where their ride is.
Vehicle identification	Anti-jamming capabilities inherent in an on-board vehicle system utilising the SBAS signals would be likely to offer a heightened degree of redundancy in vehicle tracking. This can reduce the risk of vehicle theft and improve the probability of successful vehicle recovery.
Enhanced vehicle telemetry	More granular positioning information around vehicles, can offer a more detailed overview of driving patterns and travel behaviours. This in turn has the potential to generate better-informed insurance policies, which could result in pricing efficiencies for customers and the insurance sector. It could also assist drivers in understanding the level of wear and tear on their vehicles, minimising the risk of downtime, and improving the longevity of vehicles.
Implementing vehicle technologies utilised overseas	Utilisation of SBAS signals in the region will enable vehicle systems such as e-call (a collision response service provided in-vehicle) to be brought into Australia and New Zealand. This will provide road users in both countries with a greater chance of accessing the latest technologies on offer in relation to road safety and travel efficiency, thereby reducing health and safety risks and optimising network efficiency.
Location of vehicles in remote rural areas	There is the potential to use the SBAS signals to assist in locating individuals by emergency services when in remote or poor current coverage areas, especially ambulances into rural areas. It is noted that between 50 and 75 percent of New Zealand and Australia currently has mobile blackspots (on a land-mass basis).



Logistics and fleet management

There are numerous examples of standalone GNSS integration amongst logistic management systems, for example those used by companies such as Toll, Linfox and QUBE logistics. Typically, such positioning information operates outside the parameters of precise positioning requirements with accuracies only applicable on the metre level and positioning updates not critically reliant on timing. The installation of more intelligent vehicle management systems, underpinned by precise positioning, can provide a better understanding of the vehicle's relationship to the existing road environment to drive route optimisation, fuel efficiency, machine maintenance, and driver management. Whilst there exist positioning technologies to provide enhanced logistical and fleet management, adoption of SBAS signals stands to enable similar benefits for a reduced cost to operators, thereby potentially driving greater uptake and benefits within the sector.

18.9 Utilities

Benefit	Description
Known benefits captured in analysis but applicable elsewhere	
Improved coverage of precision mapping of assets	While the focus of the analysis has remained on water assets, discussions with asset owners and spatial experts suggest that the democratisation of asset mapping data, made possible through the deployment of accessible precise positioning via an operational SBAS, stands to benefit all utility networks such as power, fibre, oil and gas, and roads.
Known benefits not captured in analysis	
Automated asset maintenance	In the long term, it is possible that network inspections will be undertaken using a variation of automated robots that will need a level of precise positioning to safely and accurately navigate the network. The SBAS signals could be used to guide such robots around utility networks, either through exposed pipes, telecommunication lines, or paved assets.

Enhanced network resilience

No single entity possesses a comprehensive overview of underground assets given the differing commercial and ownership structures. Moreover, utility network assets have been built up over numerous decades in waves meaning that there is often a technical limitation to how well asset location can be comprehensively and confidently located and known. This lack of understanding can leave networks open to the risk of failure due to deterioration, or via accidental strikes. In both instances, the flow-on effect can be large, and can have a significant impact on the social, environmental, and economic wellbeing of surrounding communities. The widespread provision of precise positioning via a system utilising the SBAS signals has the potential to 'democratise information' which means that in time a more comprehensive view of all network infrastructure can be gained. This *integrated* understanding of networks can help with asset maintenance planning, minimise the incidents of strikes, and enable faster recovery following force majeure events (for instance).

19. Detailed summary of benefits

A summary of the key findings of each economic benefit is provided in Table 10. All values are in Australian dollars and are discounted to present values over a 30-year period. In total, 44 quantitative benefits and 30 qualitative benefits have been presented. Additionally, 55 operating expenditure savings benefits, 15 health and safety benefits, three capital expenditure avoided benefits and two environmental benefits have been presented[371].

Table 10 – Economic benefits summary

Benefit	Benefit Category	Type	All figures are 30-year, NPV (AUD)			
			Total	L1	DFMC	PPP
Agriculture						
Horticulture						
Efficient deployment of horticulture inputs	Operating expenditure savings	Quantitative	98.25m	49.13m	49.13m	98.25m
Hazard and disease relocation	Operating expenditure savings	Quantitative	4.51m	4.06m	4.06m	4.51m
Reduction in crop loss to disease	Operating expenditure savings	Quantitative	6.35m	-	-	6.35m
Enhanced horticulture yield maps	Operating expenditure savings	Qualitative	-	✓	✓	✓
Broadacre						
Efficient deployment of broadacre inputs	Operating expenditure savings	Quantitative	214.02m	-	-	214.02m
Avoided cost of broadacre positioning technology	Operating expenditure savings	Quantitative	6.92m	-	-	6.92m
Enhanced broadacre yield maps	Operating expenditure savings	Quantitative	517.59m	-	-	517.59m
Non-RTK controlled traffic farming	Operating expenditure savings	Quantitative	252.15m	-	-	252.15m
Enablement of inter-row seeding	Operating expenditure savings	Qualitative	-	-	-	✓
Livestock						
Efficient pasture utilisation with virtual fencing for dairy	Operating expenditure savings	Quantitative	823.42m	823.42m	823.42m	-
Reduced livestock loss via enhanced animal tracking (predation)	Operating expenditure savings	Quantitative	79.52m	79.52m	79.52m	-
Reduced livestock loss via enhanced animal tracking (illness)	Operating expenditure savings	Qualitative	-	✓	✓	-
Forestry						
Enhanced forestry geo-referencing	Operating expenditure savings	Quantitative	57.44m	57.44m	57.44m	-
Reduction in forestry related health and safety risks	Health and safety	Quantitative	122.93m	122.93m	122.93m	-
Reduction in forestry related environmental fees and penalties	Environmental	Quantitative	9.49m	9.49m	9.49m	-
Reduced forestry road surveying costs	Operating expenditure savings	Quantitative	10.14m	10.14m	10.14m	-
Efficient use of forestry riparian margins	Operating expenditure savings	Quantitative	2.72m	2.72m	2.72m	-
Aviation						
Reduced risk of CFIT on approach	Health and Safety Avoided capital expenditure	Quantitative	246.15m 38.02m	246.15m 38.02m	246.15m 38.02m	-
Increased network reliability and the reduction of operating and passenger costs associated with weather-related diversions and delays	Operating expenditure savings	Quantitative	67.94m	67.94m	67.94m	-
Increase in successfully completed rescue and medical flights, leading to reduced morbidity and mortality	Health and safety	Quantitative	52.26m	52.26m	52.26m	-

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[371] Please note that the sum of qualitative and quantitative benefits (74) and the sum of benefit categories (75) do not align because two benefit categories have been included in the 'reduced risk of CFIT on approach' economic benefit.

Benefit	Benefit Category	Type	All figures are 30-year, NPV (AUD)			
			Total	L1	DFMC	PPP
SBAS as a backup system for ILS equipped airports	Operating expenditure savings	Qualitative	-	✓	✓	
Increasing capacity and throughput at regional airports	Operating expenditure savings	Qualitative	-	✓	✓	-
Construction						
Reduction in falls from height fatalities	Health and safety	Quantitative	8.95m	8.05m	8.05m	8.95m
Reduction in falls from height serious injuries	Health and safety	Quantitative	223.67m	201.30m	201.30m	223.67m
Reduction in vehicle collision fatalities	Health and safety	Quantitative	19.86m	17.87m	17.87m	19.86m
Reduction in vehicle collision serious injuries	Health and safety	Quantitative	190.51m	171.46m	171.46m	190.51m
Reduction in indirect costs due to vehicle collision incidents	Operating expenditure savings	Quantitative	769.97m	692.97m	692.97m	769.97m
Site surveying efficiencies	Operating expenditure savings	Qualitative	✓	✓	✓	✓
Consumer						
Reduction in labour required during the robot setup phase	Operating expenditure savings	Quantitative	33.92m	33.92m	33.92m	-
Reduction in labour required during the mapping phase using robots	Operating expenditure savings	Qualitative	-	✓	✓	-
Improved parcel delivery time	Operating expenditure savings	Qualitative	-	✓	✓	-
Reduced risk in incidents associated with trips, falls and collisions	Health and safety	Qualitative	-	✓	✓	-
Enhanced mobility, leading to greater autonomy	Health and safety	Qualitative	-	✓	✓	-
Reduction in capital and operational costs to the wider economy	Operating expenditure savings	Qualitative	-	✓	✓	-
Maritime						
Reduction in misplaced containers	Operating expenditure savings	Quantitative	28.40m	28.40m	28.40m	25.56m
Enhanced port planning	Operating expenditure savings	Quantitative	204.64m	204.64m	204.64m	184.17m
Under keel clearance management	Operating expenditure savings	Quantitative	96.50m	-	-	96.50m
Increased vessel capacity in harbour	Operating expenditure savings	Quantitative	52.87m	-	-	52.87m
Real-time hydrographic surveying	Operating expenditure savings	Quantitative	168.26m	-	-	168.26m
Lower risk real-time pilotage navigation	Operating expenditure savings	Quantitative	9.64m	-	-	9.64m
Savings in the cost of subscription services	Operating expenditure savings	Quantitative	8.84m	-	-	8.84m
Savings in replacing Australian maritime DGPS network	Avoided capital expenditure	Quantitative	18.88m	18.88m	18.88m	-
Reduction in health and safety risks on port	Health and safety	Qualitative	-	✓	✓	✓
Improved health and safety outcomes (pilots)	Health and safety	Qualitative	-	✓	✓	✓
Safety benefits for harbour users	Health and safety	Qualitative	-	✓	✓	✓
Rail						
Reduction in labour hours per maintenance task	Operating expenditure savings	Quantitative	136.09m	122.48m	122.48m	136.09m
More efficient back-office functions	Operating expenditure savings	Quantitative	56.70m	51.03m	51.03m	56.70m
Reduction in network downtime	Operating expenditure savings	Qualitative	-	✓	✓	-
Reduced headways via enablement of GNSS-based signal system	Operating expenditure savings	Qualitative	-	✓	✓	-
Resource						
Reduced collisions via enhanced CAS	Health and safety	Quantitative	2.81m	2.81m	2.81m	-
Reduction in vehicle downtime	Operating expenditure savings	Quantitative	129.97m	129.97m	129.97m	-
Improved haul truck efficiency	Operating expenditure savings	Quantitative	576.90m	576.90m	576.90m	-
Enhanced exploratory surveying efficiency	Operating expenditure savings	Quantitative	6.06m	-	-	6.06m
Enhanced shovel productivity through enhanced ore mapping	Operating expenditure savings	Quantitative	229.12m	206.21m	206.21m	229.12m

Benefit	Benefit Category	Type	All figures are 30-year, NPV (AUD)			
			Total	L1	DFMC	PPP
Improved plant operating efficiency through better material management	Operating expenditure savings	Quantitative	635.97m	572.38m	572.38m	635.97m
Reduction in environmental incidents	Environmental	Qualitative	-	✓	✓	-
Improved loader and shovel availability through more timely location	Operating expenditure savings	Qualitative	-	✓	✓	✓
Enhanced maintenance of vehicles and equipment	Operating expenditure savings	Qualitative	-	✓	✓	✓
Road						
Improved journey times via enablement of CAVs	Operating expenditure savings	Quantitative	761.13m	685.02m	685.02m	761.13m
Decreased collision risk via enhanced C-ITS safety applications	Health and safety	Quantitative	277.51m	249.77m	249.77m	277.51m
Improved journey times via C-ITS signal priority applications	Operating expenditure savings	Quantitative	45.84m	41.25m	41.25m	45.84m
Reduction in RUC administrative costs	Operating expenditure savings	Qualitative	-	✓	✓	-
Enablement of distance-based and real-time tolling	Operating expenditure savings	Qualitative	-	✓	✓	-
Enhanced mobility and accessibility for under-served populations	Operating expenditure savings	Qualitative	-	✓	✓	✓
Lowering of market barriers for safety applications	Health and safety	Qualitative	-	✓	✓	✓
Mapping efficiencies	Operating expenditure savings	Qualitative	-	✓	✓	✓
Enabling self-healing maps for CAVs	Operating expenditure savings	Qualitative	-	-	-	✓
Spatial						
Extending coverage of existing positioning networks	Operating expenditure savings	Qualitative	-	✓	✓	✓
Reducing labour requirements of cadastral surveys	Operating expenditure savings	Qualitative	-	-	-	✓
Reduced operating costs for aerial imaging	Operating expenditure savings	Qualitative	-	✓	✓	✓
Water utilities						
Reduction in accidental strikes (direct)	Avoided capital expenditure	Quantitative	17.70m	-	-	17.70m
Reduction in accidental strikes (indirect)	Operating expenditure savings	Quantitative	259.11m	-	-	259.11m
Reduced delay in underground asset digging	Operating expenditure savings	Qualitative	-	-	-	✓
Less expenditure on survey equipment	Operating expenditure savings	Qualitative	-	-	-	✓

Appendix A Acknowledgements and bibliography

A wide range of references have been drawn on in completing this economic study. Only those references that are cited in the text have been noted in this bibliography. In practice, considerably more reference documents have been considered in preparing this Economic Benefits Report.

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