SBAS TEST-BED DEMONSTRATOR FINAL PROJECT REPORT

PD8006

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1. Summary

This project aimed to assess the accuracy and precision of SBAS and PPP technologies across different farming tasks on farming properties using a range of GNSS positioning systems. In addition, this project conducted an economic survey of mixed farming enterprises throughout WA to collect data on the impact, benefits, and potential uptake of SBAS technology in small-medium mixed farming enterprises.

The project performed tests at 10 farms throughout the Corrigin region in Western Australia between May to September 2018 using a variety of SBAS and PPP receivers. Each test involved the mounting multiple SBAS and PPP capable GNSS receivers on the grower's machinery as well as one GNSS receiver operating in RTK mode and one survey prism monitored by a Robotic Total Station to both provide a source of ground truth. Measurements were to be taken whilst the grower was performing routine activities (e.g. seeding, spreading). This report outlines the methodology and data analysis in greater detail.

This project has delivered accuracy testing results of 0.5m @95% to 1.0m @95% across the range of technologies. However, we note that a number of the individual test results did deliver precisions at the 10-20cm level using various SBAS signals and we are optimistic that further system developments may deliver such results with greater consistency and reliability.

Based on the testing conducted and survey feedback from growers, over 80% of producers surveyed indicated that will need accuracies of <=10cm for high value tasks like harvesting and seeding but <=20cm for less critical high value tasks (such as spreading ameliorants and spraying chemicals) and >20cm for general tasks. Therefore, the observed accuracies do not satisfy producers needs for high value tasks and producers would be unlikely to utilise the SBAS signal until the accuracy improved or it demonstrated value-add to their existing systems (e.g. through improved reliability).

However, the survey results indicate that if free SBAS signals were available at 0.5-1.0m @95% accuracy then this would significantly benefit producers who want to do general tasks (e.g. point positing, soil sampling, livestock management, etc.). It is these areas that we believe SBAS signals will offer the greatest benefit, primarily in terms of cost, reliability, and flexibility. Further research and development (including testing) to improve kinematic precisions from future SBAS signals to <20cm @95%.

An unexpected benefit from the survey was evidence of the real value of SBAS signals for livestock businesses. It is the authors opinion that the use of SBAS signals would greatly benefit the livestock industry through enhanced livestock tracking and virtual fencing.

In addition, we experienced no difficulties (with any receiver) with connecting the SBAS Satellite and/or with receiving the correction from the SBAS Satellite. There are clearly still issues in rural areas with GNSS correction reliability. If the SBAS signals can objectively demonstrate improved GNSS correction delivery reliability, then it will certainly have something to offer to producers. Further investigation into the reliability of SBAS signals compared to NRTK corrections is required.

The project has contributed new knowledge as to the suitability of an SBAS model for agriculture, not only as a tool for advanced growers but as a means of engaging the broader farming population to consider some form of spatially-enabled agriculture. Improved and cheaper access to SBAS technologies will lead to increased efficiencies and production outcomes for Australian growers.

2. Project Objectives

The project objectives were:

- Demonstrate the positioning improvements offered by SBAS to farmers for simple positioning tasks (guidance, asset location).

- Demonstrate that the positioning improvements offered by SBAS can be accessed using low-cost off-the-shelf equipment and technology.

- Develop a mobile device application (MDA) for farmers to access and assess the positioning improvements offered by SBAS.

- Assess the accuracy of SBAS and PPP technologies in farming applications with respect to standard GNSS positioning, commercial GNSS correction services (e.g. StarFire), and Real-Time Kinematic (RTK) GNSS positioning.

- Conduct a survey of mixed farming enterprises throughout WA to collect data on the impact, benefits, and potential uptake of SBAS technology in small-medium mixed farming enterprises. The survey would make use of the analysis from previous phases of the project and provide valuable economic and behavioural information to the economic benefit study.

3. SBAS Technology

The following tables state that SBAS signals the project planned to test, the signals that were tested, and the equipment (receivers, antennae) used to perform the SBAS signal testing.

All testing in this project was completed in real-time, relevant receiver firmware versions are included in Table 1.

Table 1: SBAS Signals and Equipment Used

Signal	Equipment used	Planned to test	Actually tested
SBAS L1	BadElf	✓	1-9, 11-14
	Arrow Gold		1-2, 7-12, 14-15
	MagicUT #17 (Kernel: 4.0.0, PPP: 7.8.2)		5,6,7,10
	MagicUT #25 (Kernel: 4.0.0, PPP: 7.8.2)		8,11,12,15
SBAS DFMC	MagicUT #17 (Kernel: 4.0.0, PPP: 7.8.2)	✓	3,4,12,15
	MagicUT #25 (Kernel: 4.0.0, PPP: 7.8.2)		6,9,10,13,14
PPP over L5	MagicUT #17 (Kernel: 4.0.0, PPP: 7.8.2)	✓	8,9,11,13,14
	MagicUT #25 (Kernel: 4.0.0, PPP: 7.8.2)		3,4,5,7

Table 2: Antennae Used

Receiver	Antenna	Tests
BadElf	Internal	All
Arrow Gold	Tallysman TW3972	All
MagicUT #17	Leica AR10	All
MagicUT #25	Leica AR10	All

4. Test Plan and Methodology

4.1. Tests Planned

The project planned to perform tests at 10 farms throughout the Corrigin region in Western Australia. Each test was to consist of:

- Multiple SBAS capable GNSS receivers mounted on the grower's machinery, with each receiver tracking one SBAS signal.
- One GNSS receiver operating in RTK mode, mounted on the grower's machinery, to provide a source of truth.
- One survey prism monitored by a Robotic Total Station, mounted on the grower's machinery, to provide a source of ground truth.
- Measurements were to be taken whilst the grower performing routine activities (e.g. seeding, spreading).

The tests were originally planned to occur in May-June 2018. Due to equipment availability (refer to previous reports) the testing was conducted in May 2018 and September 2018.

4.2. Tests Conducted

The project conducted 15 tests, five more than originally planned. The tests were conducted at 10 different farms throughout the Corrigin region. The vast majority (13) of the tests were conducted in September 2018 with the remaining tests having been conducted during an earlier visit to the region in May 2018.

Table 3: Summary of tests completed

Tests	Test description	Start	End	Receivers	Equipment
1	Signals: L1 Validation: NRTK, RTS Guidance: App	04/05/18	04/05/18	3	BadElf Arrow Gold CHC i80
2	Signals: L1 Validation: NRTK, RTS Guidance: Autosteer	05/05/18	05/05/18	3	BadElf Arrow Gold CHC i80
3	Signals: L1, DFMC, PPP Validation: RTS Guidance: Autosteer	11/09/18	11/09/18	3	BadElf MagicUT x 2
4	Signals: L1, DFMC, PPP Validation: RTS Guidance: Autosteer	11/09/18	11/09/18	3	BadElf MagicUT x 2
5	Signals: L1, PPP Validation: RTS Guidance: Autosteer	12/09/18	12/09/18	4	BadElf Arrow Gold MagicUT x 2
6	Signals: L1, DFMC Validation: RTS Guidance: Autosteer	12/09/18	12/09/18	4	BadElf Arrow Gold MagicUT x 2

Tests	Test description	Start	End	Receivers	Equipment
7	Signals: L1, PPP Validation: NRTK, RTS Guidance: Autosteer	13/09/18	13/09/18	5	BadElf Arrow Gold MagicUT x 2 CHC i80
8	Signals: L1, PPP Validation: RTS Guidance: Autosteer	13/09/18	13/09/18	4	BadElf Arrow Gold MagicUT x 2
9	Signals: L1, DFMC, PPP Validation: NRTK, RTS Guidance: Autosteer	13/09/18	13/09/18	5	BadElf Arrow Gold MagicUT x 2 CHC i80
10	Signals: L1, DFMC Validation: NRTK, RTS Guidance: Autosteer	14/09/18	14/09/18	5	BadElf Arrow Gold MagicUT x 2 CHC i80
11	Signals: L1, PPP Validation: NRTK, RTS Guidance: Autosteer	14/09/18	14/09/18	4	Arrow Gold MagicUT x 2 CHC i80
12	Signals: L1, DFMC Validation: NRTK, RTS Guidance: Autosteer	15/09/18	15/09/18	4	BadElf MagicUT x 2 CHC i80
13	Signals: L1, DFMC, PPP Validation: NRTK, RTS Guidance: Autosteer	15/09/18	15/09/18	5	BadElf Arrow Gold MagicUT x 2 CHC i80
14	Signals: L1, DFMC, PPP Validation: NRTK, RTS Guidance: App	15/09/18	15/09/18	5	BadElf Arrow Gold MagicUT x 2 CHC i80
15	Signals: L1, DFMC Validation: NRTK, RTS Guidance: Autosteer	16/09/18	16/09/18	4	Arrow Gold MagicUT x 2 CHC i80

4.3. Testing Methodology

4.4. Generic Test Method

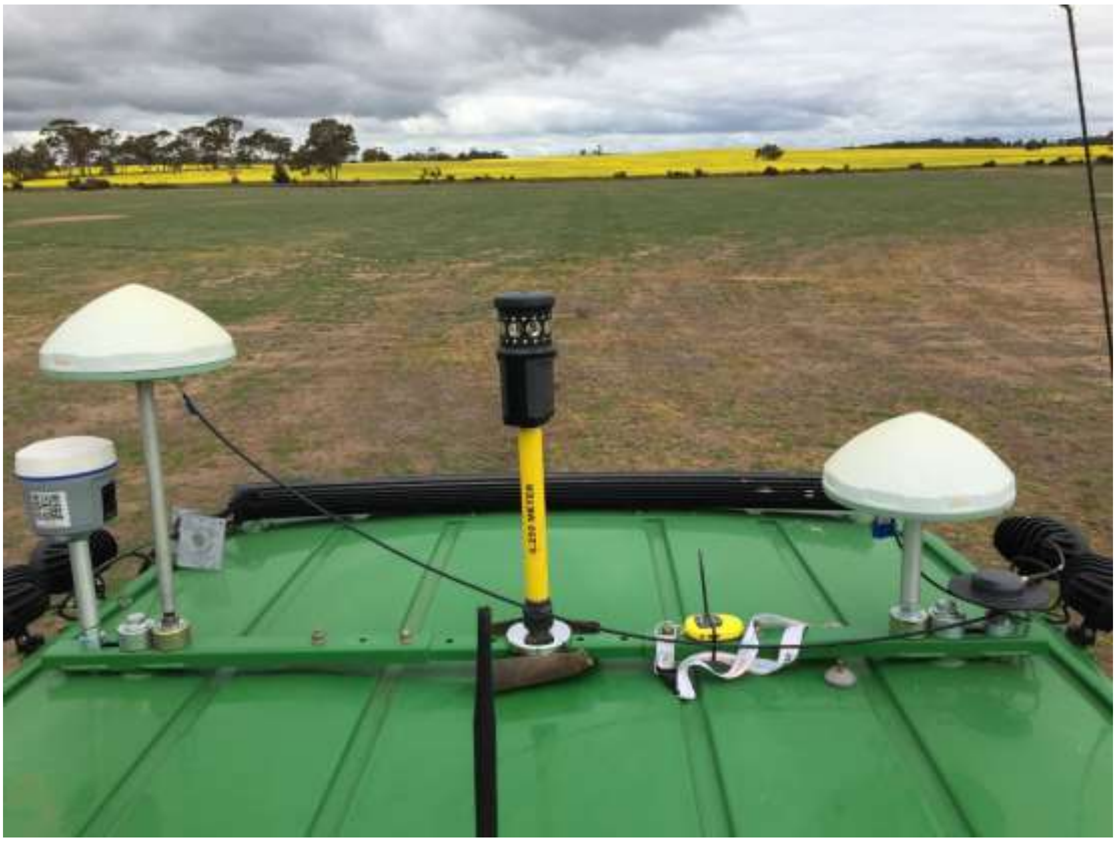
Each test was conducted according to the following method:

1. Place two survey marks approximately 20-50m apart. The marks should be placed to:
    a. Minimise obstruction (primarily dust) whilst the machinery is moving.
    b. Maximise GNSS observing conditions.
    c. Minimise the angular motion of the robotic total station.
2. Determine the coordinates of the survey marks using NRTK GNSS in a static observation mode (minimum of five minutes occupation).
3. Setup a robotic total station (RTS) over one of the survey marks and backsight to the other, thereby verifying the NRTK GNSS derived coordinates.

4. Attach a 360° survey prism to the machinery. Where possible, co-locate the survey prism with the machineries autosteer GNSS receiver. The survey prism will provide the primary "truth" observation for the test.
5. Attach the NRTK GNSS receiver to the machinery. The NRTK GNSS receiver will provide the secondary "truth" observation for the test.
6. Attach test receivers / antennae to machinery.
7. Measure the horizontal offsets from the survey prism to the NRTK GNSS receiver and each of the test receivers / antennas. Note that a positive offset is to the *right* of the survey prism (in the direction of travel of the machinery) whilst a negative offset is to the *left* of the survey prism.
8. Commence RTS tracking and logging of the survey prism at a distance interval of 5m.
9. Commence GNSS receiver logging at an interval of one second.
10. Commence machinery operations using the chosen guidance method (Autosteer or MDA)
11. Complete machinery operations.
12. Complete GNSS receiver logging and RTS tracking.
13. Check horizontal offsets.
14. Dismantle equipment.

A typical machinery setup from the testing is shown in Figure 1.

Figure 1: Typical Equipment Setup



4.4.1. Variations

The generic test method described above was not varied.

4.5. Incomplete Tests

There were no incomplete tests.

5. Testing Challenges

The challenges experienced during testing were related to the timing/availability of equipment and personnel or technical issues related to the equipment.

5.1. Hardware: MagicUT Certification

The unavailability of the MagicUT, due to certification issues, had a significant impact on the project's ability to undertake the planned testing. The original project plan called for testing from May-July with the analysis to be completed in time for the interim report (August 2018). The certification issues delayed the majority of the testing (Tests 3-15) by approximately two months.

In late April it became apparent that the MagicUT was unlikely to be available in May. Rather than delay the testing entirely the project team decided to undertake some initial testing without the MagicUT, using L1 Legacy SBAS equipment only. This testing was successful (Test 1-2) and helped the project team to confirm the testing protocols for the subsequent testing with the MagicUT.

Once the MagicUTs became available a second round of testing (Tests 3-15) was conducted in September. The project milestones and deliverables were modified accordingly.

5.2. Project: Practical & Efficient On-Farm Testing

It quickly became apparent during the initial testing (May 2018) that repeated treatments over the same area on the farm was impractical for various reasons, including:

- Farmers wanting to combine the testing with activities such as spraying, seeding.
- Time wasted coupling / uncoupling heavy equipment to the tractors (e.g. sprayer).
- Limited availability of machinery.
- Prevalence of autosteer among the participants.

To overcome these issues the project team determined that the most efficient method for obtaining the required treatments was to mount as much equipment as possible on the machinery. As such, multiple receivers / antennae were attached to the machinery and a single pass conducted over the test area. Thus, all treatments were obtained simultaneously, rather than one at a time.

The benefits of this change to the original testing method was that the testing became more efficient and there was less of an imposition upon the test participants. There was no impact on the ability of the project team to evaluate the accuracy of the various treatments due to this change in the test method. The drawback of the change in testing method is that the participant receiver less direct exposure to the effects of the different treatments, as they do not undertake navigation guidance using each treatment. However, given that the majority of the participants already have an autosteer capability (at the 0.25 – 1m level) this is not a significant loss.

Note that this testing challenge did not delay the project, nor did it reduce the ability of the project team to objectively asses the accuracy of the various SBAS signals.

5.3. Hardware: NRTK Availability

To provide an additional source of "truth" data the test method included a survey-grade GNSS receiver to provide an NRTK positioning solution. In order to obtain NRTK positions the survey-grade receiver (in this case, a CHC i80) must have access to a suitable network of continuously operating reference stations (CORS). For this project, SmartnetAUS was the chosen network as it was the only network that appeared to provide NRTK services in the project area.

During the first round of testing (May 2018) it became evident that the NRTK solution was not performing to expectations. This continued in the later testing period (September 2018). The primary issues were:

- Inability to resolve integer ambiguities and obtain a fixed (cm-level) solution.
    - Primarily an issue during real-time operations on the machinery.
    - Overcome for placing survey marks (Section 4.4) by longer occupation times.
- Occasional poor mobile phone coverage (unreliable / discontinuous NRTK service).
- Space issues when mounting. Equipment not always optimally located.

As a result of these issues the NRTK solutions obtained during machinery operations were predominately float solutions (unresolved integer ambiguities) with precisions in the order of decimetres rather than centimetres expected for a fixed solution. Aggressive data cleaning and outlier removal improved the obtained precisions, but the large amount of data removed (~50% of the data in some tests) are indicative of the unreliable performance of the NRTK solutions.

The consequence of this issues encountered with the NRTK solutions is that the secondary "truth" data that was expected to be available is unreliable and of poor quality. Thus, the NRTK solutions have not been treated as a source of truth in the analysis (Section 6.4.3) but merely as another means of comparison for the tested SBAS signals.

The project team does not consider the unreliability and poor quality of the NRTK solutions to be a major concern in the analysis. The NRTK solutions were included to serve as a secondary (backup) truth dataset and their loss in this regard is not critical, given the primary truth dataset (robotic total station) was available in all the tests performed.

The issues experienced by the project team with the NRTK solutions serves to highlight one of the *benefits* of SBAS technology, namely that SBAS technology is not dependent on mobile phone coverage and as such would provide a more reliable service in remote areas such as Corrigin.

5.4. Hardware: Equipment Issues

There were occasions during the testing where data was not obtained or was unusable due to:

- No mobile phone coverage (CHC i80).
- Receivers shaking loose from their mountings (multiple).
- Data logging failure (Arrow Gold).
- Human error (Arrow Gold, RTS).

These issues were isolated and were unpredictable (apart from the mobile phone coverage). In all cases there was sufficient data available from other receivers to ensure that the effected tests were still a success.

6. Test Results and Analysis

6.1. Results Summary

The results summary is provided in two parts:

- An aggregate of all the tests conducted, for each SBAS (or GNSS) technology.
- An aggregate of the tests considered to be reliable, for each SBAS (or GNSS) technology.

6.1.1. Results Summary – All Tests

Table 4: Results Summary – All Tests

	SBAS L1						**DFMC**		**PPP (L5)**		**NRTK**	
	BadElf		*Arrow Gold*		*MagicUT*		*MagicUT*		*MagicUT*		*CHIC i80*	
	Mean	StdDev	Mean	StdDev	Mean	StdDev	Mean	StdDev	Mean	StdDev	Mean	StdDev
Mean	**0.05**	**2.04**	**-0.10**	**0.42**	**0.02**	**0.21**	**0.09**	**0.41**	**-0.14**	**0.38**	**0.18**	**0.17**
Min	-2.66	0.33	-0.83	0.17	-0.01	0.08	-0.06	0.07	-1.25	0.14	-0.07	0.03
Max	2.28	5.51	0.09	0.97	0.05	0.42	0.51	1.08	0.09	0.87	1.27	0.74
Tests	13	13	10	10	8	8	9	9	8	8	9	9

6.1.2. Results Summary – Reliable Tests

Table 5: Results Summary – Reliable Tests

	SBAS L1						**DFMC**		**PPP (L5)**		**NRTK**	
	BadElf		*Arrow Gold*		*MagicUT*		*MagicUT*		*MagicUT*		*CHIC i80*	
	Mean	StdDev	Mean	StdDev	Mean	StdDev	Mean	StdDev	Mean	StdDev	Mean	StdDev
Mean	**-0.18**	**2.38**	**0.01**	**0.39**	**0.04**	**0.38**	**0.04**	**0.23**	**0.02**	**0.47**	**#N/A**	**#N/A**
Min	-1.25	0.68	-0.22	0.17	0.03	0.34	0.01	0.21	-0.11	0.21	#N/A	#N/A
Max	0.88	3.35	0.08	0.97	0.05	0.42	0.08	0.25	0.09	0.87	#N/A	#N/A
Tests	6	6	6	6	2	2	2	2	5	5	0	0

6.2. Data analysis methodology

A generic data analysis method was developed and implemented on each test. The method was designed to have the minimal possible manual intervention.

Table 6: Data Analysis Method

Step	**Process**	**Details / Notes**
1	Align data set reference frames to ITRF14	Data collected by the CHC i80 (NRTK) and Robotic Total Station (RTS) was transformed to ITRF14 using a 14-parameter transformation. Data collected from other equipment (BadElf, Arrow, MagicUT) was collected in either ITRF14 or WGS84 and was not transformed. Note that WGS84 and ITRF14 are equivalent at the mm-level.
2	Create an alignment for each data set.	Using AutoCAD, an alignment was created from the point data contained within each data set. The alignment is created by joining sequential points using an AutoCAD 3D polyline.

Step	Process	Details / Notes
3	Select the "truth" alignment.	In all test, except AE1, the truth alignment was the alignment produced from the RTS data set. In the case of AE1 the RTS performance was poor (due to prisms placement and dust). The alignment produced from the NRTK data set was used in this test.
4	Compute the horizontal offset of each point in an alignment from the truth alignment.	Using AutoCAD's Station and Offset Report tool each alignment (e.g. BadElf) is compared to the truth alignment. The station (chainage / running distance) and offset (horizontal and vertical) from the truth alignment is computed for each point in the alignment. The report generates a spreadsheet for each alignment (see attached).
5	Correct horizontal offsets for antenna mounting position.	Each antenna (e.g. BadElf, Arrow, MagicUT) was positioned at a fixed horizontal offset from the source of truth (survey prism). The horizontal offsets computed in the previous step need to be corrected for this additional offset.
6	Summary statistics and outlier removal.	Summary statistics for each alignment were computed in Excel. The summary statistics were used to iteratively remove outliers based on a 95% confidence level. Outliers were removed iteratively until no outliers were detected. The VBA code used to remove the outliers is attached.
7	Final summary statistics	The summary statistics available at the end of the outlier removal process represented the final summary statistics.

6.3. Detailed Results

Table 7 contains the summary statistics for each test. The individual test results, including the outliers removed, can be found in the appendices.

Table 7: Detailed Results – Summary Statistics

	SBAS L1						DFMC		PPP (L5)		NRTK	
	BadElf		Arrow Gold		MagicUT		MagicUT		MagicUT		CHIC i80	
Test	**Mean**	**StdDev**	**Mean**	**StdDev**	**Mean**	**StdDev**	**Mean**	**StdDev**	**Mean**	**StdDev**	**Mean**	**StdDev**
AE1	-0.25	0.68	0.01	0.41								
AE2	-0.28	3.35	0.03	0.25							0.00	0.06
AE3	2.28	0.88					-0.06	0.84	-1.25	0.29	1.27	0.15
AE4	-1.25	2.37					0.05	1.08	0.06	0.87		
AE5	0.02	0.73			0.05	0.13			-0.11	0.33		
AE6	-0.28	2.04			0.03	0.34	0.11	0.26				
AE7	-2.66	3.41	-0.08	0.48	0.00	0.09			0.00	0.14		
AE8	-0.19	1.66	0.09	0.28	-0.01	0.08			0.00	0.36		
AE9	0.25	1.57	-0.22	0.17			0.01	0.25	0.02	0.27	-0.03	0.08
AE10			-0.06	0.27	-0.01	0.12	0.51	0.55			0.18	0.14
AE11	1.29	2.23	0.03	0.59	0.05	0.29			0.09	0.57	0.29	0.74
AE12	0.88	5.51	0.08	0.46	0.01	0.18	-0.01	0.08			-0.04	0.06
AE13	0.40	0.33					0.08	0.21	0.04	0.21	0.01	0.03
AE14	0.36	1.76	-0.83	0.97			0.04	0.07			0.02	0.03
AE15			-0.03	0.35	0.05	0.42	0.06	0.35			-0.07	0.25

6.4. Discussion

6.4.1. Reliability

During the outlier removal processing (Section 6.2) large numbers of outliers were removed from a number of tests in order to satisfy the 95% confidence interval limit. The percentage of data removed as outliers varied significantly, from 0% to 57%, between and within tests. The number of outliers removed was concerning and further investigations was considered necessary.

The only consistent pattern observed in the number of outliers removed was that the NRTK results always contained significant numbers of outliers (varying from 18% to 57%). There were no other obvious patterns in the outlier removals. For the NRTK results we consider the large number of outliers to be a function of the variable and unpredictable NRTK performance during the tests. The NRTK position solutions varied between "Fixed" and "Float" throughout each test and we consider this to be the most likely cause of the outlier removals. The results could be improved by pre-eliminating either the "Fixed" or "Float" solutions from the analysis, but this would have required significant additional processing, which we determined as unnecessary given the NRTK results were not the focus of the project.

Despite examining the SBAS enabled receiver results no clear patterns or explanations were found for the tests where large numbers of outliers were removed. It does appear that the MagicUT experienced greater numbers of outliers whilst utilising the L1 SBAS signal but did not do so consistently or with significantly larger average percentages of outliers (17%) than when utilising the DFCM signal (11%) or PPP (L5) signal (9%).

The large number of outliers removed, the lack of clear patterns in their occurrence, and no clear reasons for their occurrence (with the exception of the NRTK results) has led us to present the test results in two categories:

> **All Test Results (Section 6.1.1)**
>
> All tests, regardless of the number of outliers removed, are included in these statistics. As such we consider that they represent the "worst case" from a reliability perspective.
>
> **Reliable Test Results (Section 6.1.2)**
>
> Only tests where the percentage of outliers removed (~5%) reflects the 95% confidence limit are included in these statistics. Our logic is that these tests represent the "best case" from a reliability perspective.

In the remainder of the discussions we will be referring to statistics from the "Reliable Test Results" unless otherwise noted.

6.4.2. BadElf Performance

Of the receivers tested the BadElf was the cheapest and least capable receiver. As such, it was expected to provide the worst performance. The results clearly indicate that this was the case, with the precision of the BadElf receiver in the order of five time worse than the other receivers tested. However, the magnitude of the disparity was surprising to the team. Expectations at the beginning of the project were that the BadElf would be capable of delivering a precision of ±2.5m @95% in a kinematic environment

(BadElf, 2018). The results indicate that the BadElf precision in a kinematic environment was in the order of ±4.0 to ±4.8 m @95%, significantly worse than expected.

We attribute the poor performance of the BadElf to the conditions in which the receiver was required to operate during the tests. We consider these conditions to be at the extremes of the receivers operating capabilities and include:

- Harsh kinematic environment (dust, vibration).
- Sub-optimal mounting conditions (clear sticky tape wrapped around the receiver).
- Reasonable likelihood of multipath or signal blockage from other receivers in the test array.

The results obtained and the subjective experience of using the BadElf has led the project team to the conclusions that the BadElf receiver is not suited to the task of navigation guidance in an agricultural environment (even with access to SBAS signals).

Further discussion and analysis in this section **does not** consider the BadElf receiver. Any further reference to "receivers" excludes the BadElf.

6.4.3. NRTK Performance

The NRTK solution performance was significantly worse than expected. Generally, for whilst operating in kinematic mode, only a float solution was available. Fixed solutions, when obtained, were unreliable and tended to in and out. The poor performance of the NRTK solution was not a major problem for the project, as it was included as an additional source of comparison and/or a secondary truth dataset.

The poor performance of the NRTK solutions did not appear to be a function of the mobile phone coverage which was of sufficient strength to provide NRTK solutions. This was demonstrated by the fact that all the robotic total station control points were observed using fixed NRTK solutions. These solutions, however, were for a static receiver (10-15 minutes) as opposed to a receiver mounted on a kinematic platform.

The SmartnetAUS service used to provide the NRTK solution indicates that cm-level positioning should be available at all the test sites. However, it was clear from the test results that this was not the case in a kinematic scenario, fixed cm-level solutions were only reliably obtained when performing static surveys.

Finally, the NRTK performance was also influenced by the antenna mounting options available on the farming equipment. In a number of cases the CHC i80 was partially shadowed by other receivers. This is likely to have a detrimental effect on the NRTK performance.

Whilst the NRTK performance rendered the results useless for comparison purposes they do highlight a key strength of the SBAS signals and technology. That is, the signals are available in any area (regardless of mobile phone coverage) and significant less ground infrastructure is required to service large areas. It was clear to the project team that SBAS (i.e. satellite delivery) has advantages when operating kinematically in the test area in terms of cost, infrastructure, simplicity, and reliability.

6.5. SBAS Performance

6.5.1. Accuracy

The accuracy of the various receivers and SBAS signals can be assessed by examining the mean horizontal offset from the truth alignment, summarised in Table 5. Receivers utilising the SBAS signals were within a few centimetres (1-4cm) of the truth alignment. Whilst the expected value for the mean horizontal offset would be zero (indicating results that were entirely free of systematic bias) we consider the 1-4cm differences to be acceptable for the following reasons:

Receiver & Prism Mounting:

The receivers and survey prism were mounted differently in each test due to variations in the tractor and mounting rails/brackets available. Mounts varied from magnets (survey prisms, some receivers) to bolts (receivers) and sticky tape (BadElf).

Whilst care was taken to mount the equipment as tightly as possible the receivers and prisms did move throughout the tests. Measurements taken before and after the tests indicate that the relationship between the prism and receivers varied by 1-2cm as a result of vibration, shaking, and jolts during a test.

We consider that the lack of stability in the receiver and prism mounts has contributed to the small differences (1-4cm) seen in the mean horizontal offsets.

Magnitude of the differences

The magnitude of the differences from the expected zero mean are small (1-4cm) relative to the precisions obtained (20-50cm). Whilst the differences are indicative systematic biases, we believe they can be accepted given their size and the numerous possibilities for small systematic biases to remain in the testing (e.g. processing technique, internal antenna phase centre offsets, unstable mounting, multipath, and so forth).

Based on the results and the discussion above we are reasonably confident that the precision of the results (Section 6.5.2) can be treated as a reliable and unbiased indicator of the receiver and SBAS signal performance.

6.5.2. Precision

The precision of the various receivers and SBAS signals can be assessed by examining the standard deviation of the horizontal offset from the truth alignment, summarised in Table 5. Receivers utilising the SBAS signals obtained precisions of **0.45m to 0.95m** @ 95%, in both the "reliable" and "all" test categories.

The performance of the L1 Legacy signals was consistent with expectations (<1m @95%) and the receivers utilised (Arrow Gold & MagicUT) to access this signal also produced similar precisions (0.78m and 0.76m @95%).

The performance of the DFMC signals (0.45m @95%) was better than expected (<1m @95%) but the small number of reliable tests (two) using this signal is not ideal. The results from all the tests with this signal (nine tests, 0.82m @95%) indicate that the DFMC solution was performing as expected, rather than better than expected.

The performance of the PPP signals (0.95m @95%) was worse than expected (<0.5m @95%). The project team expected the PPP results to provide the best precisions from of the SBAS signals tested, but the results indicate otherwise. There is a large variation in the precisions obtained across the eight tests (0.28m @95% to 1.64m @95%) which may be indicative of instability in the PPP solution, the kinematic nature of the tests, or the field procedures adopted.

The PPP solution is unlikely to have been heavily influenced by the environment of the test sites (open paddocks) but the operational procedures the project adopted may have had an impact. To minimise the impact on the farmers operations the MagicUTs were installed on the farming equipment whilst it was being prepared for use. Thus, the time available for the PPP solution to converge varied and in most cases was probably insufficient for the solution to fully converge. Our field procedure may have contributed to this problem, as kinematic operations were commenced once all the available satellites were locked (rather than allowing a set period of time for convergence).

Apart from the PPP solutions the obtained precisions meet or slightly exceed the original expectations and appear to be reasonably consistent across the various tests and receivers.

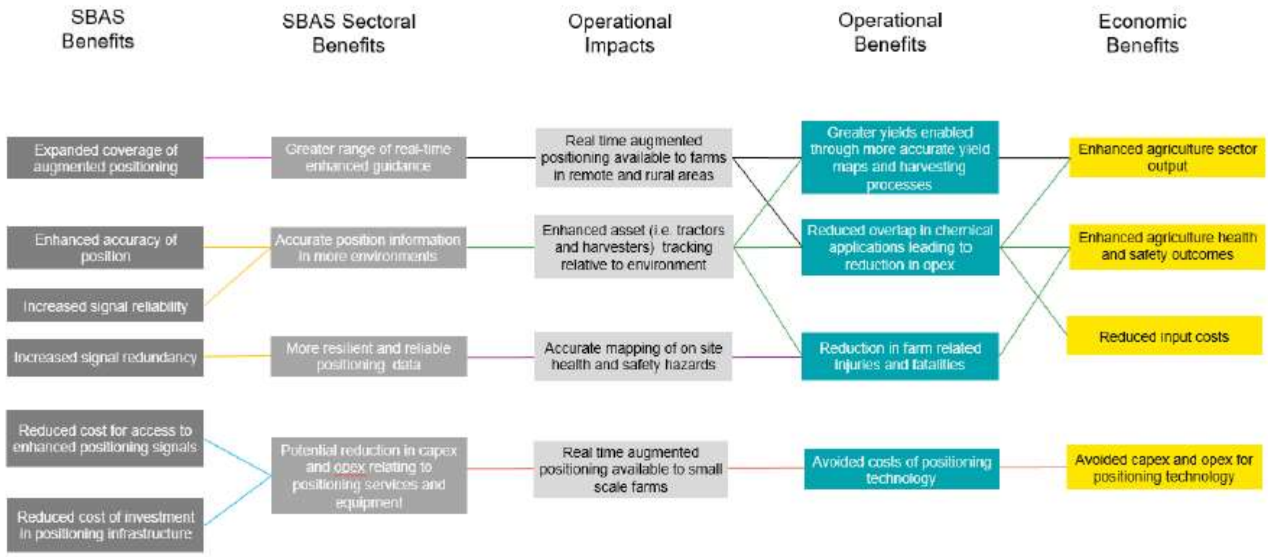
7. Economic Benefits

7.1. Perceived Benefits and Survey Results Summary-

During Phase 3 of this project, the Corrigin Farm Improvement Group (CFIG) conducted a comprehensive survey of WA mixed farming enterprises. This survey captured the views of WA growers across a wide range of geographical locations, farm size, and current GNSS usage and capabilities. Refer to the CFIG survey report and interim report for further details on the methodology and analysis.

In consultation with CFIG, the EY and Frontier SI team compiled a perceived benefits map (Figure 2). This map of realistic impacts and benefits underpinned the development of the Producer Survey questions. Of all the benefits listed- the only one that CFIG did not believe could be quantified by the producer survey was 'reduction in farm related injuries and fatalities' so questions were not framed to address this. It must be noted that the data from the accuracy testing was not available prior to the distribution and finalisation of the survey so no there was no opportunity for the results to influence producer responses.

Figure 2: Perceived Benefits Map



The majority of the respondents who participated in this survey were using some form of GPS for either all or some of the following tasks: seeding, spraying, spreading or harvesting. This survey was sent across the WA mixed farming network and despite actively searching for producers who do not use any or minimal GPS, only 2/67 respondents were not using any GPS. In WA, there has been a good uptake of GPS technologies across the state (Llewellyn and Ouzman 2014). Irrespective, this survey has provided good feedback from producers who currently use GPS technology and the responses demonstrate the role of SBAS for mixed farmers.

The survey report and raw and cleaned data was distributed to Ernest and Young (EY) and the CFIG team hope that the results will provide essential information on the benefits and opportunity cost of

SBAS technology for the agricultural sector. The delivery of the survey data- both quantitative farm business information and behavioural responses- to the EY team will be vital to providing validation and scale to the benefits mapping that will be undertaken by EY.

In summary, the results from the survey are as follows:

- A significant portion of the respondents did not believe that they had adequate coverage of GNSS signals with 30% of producers in this group indicating that they experienced over 10cm of accuracy on their property.
- Producers want the highest accuracy for seeding followed by harvest then spraying/spreading.
- The majority of producers have indicated that they ultimately desire GNSS accuracy of <10cm irrespective of task.
- Although the majority of producers do not believe they are over-applying chemical and fertiliser there was still ~30% of producers who believe they are over-applying >10cm.

7.2. Realised Economic Benefits -

This section aims to contextualise the results from the economic benefits survey with the testing results (Section 6). The test results obtained by the project team have been able to validate a number of the perceived economic benefits (Section 7.1).

7.2.1. High Value Farming Tasks

The tested SBAS signals did not provide the precision required for high value farming tasks.

The economics benefit survey asked producers what level of accuracy they required for different farming tasks. The results indicate that:

1. Producers want <10cm accuracy for harvesting, seeding, and spraying (high value tasks).
2. Over 79% of respondents prefer better than 10cm accuracy, 18% from 10 to 20cm, and only 2.5% >20cm.
3. There was a strong response to the question about why producers were not adopting GNSS technology - with positioning accuracy and cost being the key reasons.

The important conclusion that can be drawn from the survey results is that if the SBAS signals can provide <=10cm accuracy then uptake of technologies utilising the SBAS signal could be widespread.

The test results indicate that the average signal precision was between 30-50cm (one standard deviation). This is outside the producers desired accuracy range (<20cm for 9% of producers) and well outside the desire accuracy for high value tasks (<10cm for 79% of producers). Thus, widespread utilisation is unlikely to occur at the precisions observed in the test results. However, we note that a number of the individual test results **did** deliver precisions at the 10-20cm level using various SBAS signals and we are optimistic that further system developments may deliver such results with greater consistency and reliability.

7.2.2. General Farming Tasks

The tested SBAS signals did provide precision required for a range of agricultural practices

The original primary objective of this project was to demonstrate the positioning improvements offered by SBAS and PPP to producers for simple positioning tasks. This project has achieved this as an outcome of the survey and testing. A number of respondents indicating that they would be willing to compromise on accuracy for certain on-farm tasks (Question 21). If industry is supported to develop generic SBAS/PPP based technologies for these tasks (e.g. point positioning for soil sampling or hazard identification, livestock management, pedigree matchmaking, virtual fencing) then producers will rapidly make use of such technologies. The test results indicate the tested SBAS signals do offer positioning improvements (to 30-50cm) that would support the further development (and thus, utilisation) of these technologies.

7.2.3. GNSS Correction Reliability

The tested SBAS signals were reliable.

An important outcome of the survey was the finding that 30/50 respondents did not believe that they had adequate GNSS correction coverage. Of these 30 producers, 15 indicated that they felt the lack/unreliability of the GNSS correction coverage resulted in their positioning accuracy degrading to >10cm. The results are further supported by comments from the producers on the high 'dropout' rates they were experiencing with their current RTK or other GNSS systems.

The testing in this project was not specifically designed to assess GNSS correction availability/reliability (as opposed to positioning reliability). However, it is possible to report, subjectively, on the project team's experience during the testing with regard to GNSS correction availability and reliability. Our experience was that NRTK GNSS corrections delivered via mobile phone were not reliable and were only effective (cm-level positioning) when operating statically. In contrast, we experienced no difficulties (with any receiver) with connecting the SBAS Satellite and/or with receiving the correction from the SBAS Satellite.

There are clearly still issues in rural areas with GNSS correction reliability. If the SBAS signals can objectively demonstrate improved GNSS correction delivery reliability, then it will certainly have something to offer to producers.

7.2.4. Reduced Chemical Inputs

The tested SBAS signals would not deliver the precision required to reduce chemical inputs.

When asked if producers believed they were over applying chemical and fertiliser, 56% of respondents did not believe they were. However, when producers were asked to categorise their over-spraying of chemical and over-applying of fertiliser, the majority of producers believed they were over-applying only by a minimal amount or <10cm - with 88% for chemical and 70% for fertiliser. However, there are still 30% of producers who believe they are over-applying fertiliser (>10cm) and would benefit from improved accuracy. To be effective (in the producer's view) accuracies would need to be <10cm which the test results indicate would not be possible from the tested SBAS signals.

7.2.5. Improved Yield Mapping

The tested SBAS signals were reliable, consequently they may improve yield mapping reliability.

The number of producers collecting and downloading yield maps in the survey was significantly higher than those who were not. However, many of the producers who did download their yield maps were not necessarily doing anything with the data - simply downloading to possibly use later on when their technical expertise improves. The key reason for not utilising this mapping data for other purposes was due to a lack of technical capability with only 2/45 answers indicating that positioning accuracy was a barrier to adoption. Similar adoption levels and barriers to adoption were observed in a recent survey of precision agriculture adoption in Western Australia by Llewellyn and Ouzman (2014). The benefits of SBAS for the producers already collecting and utilising yield maps will come indirectly through enhanced positioning accuracy of the yield values within each pixel. As mentioned previously, over half of the respondents experienced >10cm accuracy on their property as a result of unreliable GNSS correction services. In this context, if the reliability and accuracy of yield data improves as a result of reliability improvements delivered by SBAS it will lead to improved farm productivity through enhanced amelioration practices and lower input costs potentially.

7.3. Benefits Discussion

This project has delivered accuracy testing results that have met our original expectations (0.5m @95% to 1.0m @95%). Although the observed accuracies do not satisfy producers needs for high value tasks such as harvesting, spreading and seeding, the project has reinforced to industry the need for reliable positioning technologies that can deliver accuracies of <10cm. Over 80% of producers surveyed indicated they required <10cm and as such they would be unlikely to utilise the SBAS signal until the accuracy improved or it demonstrated value-add to their existing systems (e.g. through improved reliability). Interestingly, for those producers without an auto-steer capability the survey indicated that they would be accept lower accuracies (equivalent to those demonstrated in the testing) for high value tasks. This indicates that for those producers without expensive auto-steer capabilities something (SBAS delivering 0.5m @95%) would be better than nothing!

The survey results indicate that if free SBAS signals were available at 0.5-1.0m @95% accuracy then this would significantly benefit producers who want to general tasks (e.g. point positing, soil sampling, livestock management, etc.). The level of accuracy demonstrated in the testing will provide significant value to these general tasks.

An unexpected benefit from the survey was evidence of the real value of SBAS signals for livestock businesses. It is the authors opinion that the use of SBAS signals would greatly benefit the livestock industry through enhanced livestock tracking and virtual fencing. The following comments exemplifies this statement:

> *"I really need livestock positioning devices using SBAS that can be attached and monitored to my stock to allow paddock use assessment, progeny matching, maternal qualities and behaviour, movement modelling, etc to be assessed to allow me to make better breeding and feed management decisions."*

"Absolutely. Exactly what I need is a cheap way to track the movements of my stock individually for the previously stated reasons. 20cm would generally be accurate enough for my needs, and because I need lots of devices cost is critical. Present commercially available technology is financially unviable with all the needs I desire although it is".

8. Networking and Partnerships

This project was well supported by the network of members from the Corrigin Farm Improvement Group (CFIG). All farmers CFIG speak to about the project believe that there are likely impacts and opportunities that will arise for their business from having access to SBAS. They were made aware of the lower accuracy compared to RTK systems and that this was a Testbed project but interest was still high.

The equipment and project was discussed at a number of field days and the producers are anticipating follow up on these results at their post-trials discussion day in 2019.

CFIG have seen a lot of value from being involved in this project and the skills, knowledge and contacts gained from the project would contribute significantly to future research work in this area, should the opportunity arise. CFIG are particularly interested in further work using SBAS for livestock production.

CFIG also aims to utilise the SBAS app for soil sampling point positioning and accurate identification of critical locations, for example the boundaries of unmarked field trial sites (seeding, fertility trials). Other grower groups in WA may also be interested in utilising this app.

9. Key Findings and Recommendations

9.1. Key Findings

9.1.1. Applications Tested and Accuracy Needs

Currently, growers with commercial off-the-shelf (COTS) non-RTK, non-subscription autosteer equipment obtain accuracies of ~0.1m. Our original expectations were that this level of accuracy could not be reliably achieved with any of the tested signals. The level of accuracy initially anticipated from the SBAS signals was 0.5 – 1.0m @95%, significantly worse than available from growers COTS systems. These expectations of the SBAS signal were largely confirmed by the testing completed as part of this project. We believe that the testing results and survey feedback clearly demonstrate that the SBAS signals should not be attempting to compete with or replace COTS systems at the <10cm level.

However, whist the COTS systems are widespread and grower's accuracy expectations are driven by COTS system performance, they are aimed at high value tasks (harvesting, sowing, spreading) and as a result are expensive and lack flexibility. Based on the testing conducted and survey feedback from growers, we believe that growers will need accuracies of <=20cm for less critical high value tasks (such as spreading ameliorants and spraying chemicals) and >20cm for general tasks. It is these areas that we believe SBAS signals will offer the greatest benefit, primarily in terms of cost, reliability, and flexibility.

Our thoughts with regards to grower's accuracy requirements changed over the course of the year. In particular we recognised different levels of accuracy are needed for different tasks (although this is not necessarily recognised by the growers). With increasing adoption of cm-level NRTK technology by growers (particularly in WA) future SBAS signals need to deliver as close as possible to cm-level accuracies. If reliable performance at accuracies of<20cm can be achieved, the reduced costs associated with SBAS may encourage some farmers to compromise on accuracy for high value tasks.

9.2. Recommendations

Based on the testing results and survey feedback we have two recommendations:

- Further research and development (including testing) to improve kinematic precisions from future SBAS signals to <20cm @95%.
- Further investigation into the reliability of SBAS signals compared to NRTK corrections.

10. Conclusion

This SBAS testbed project has obtained SBAS signal accuracies levels of 0.5-1.0m @95% whilst conducting various farm tasks on farming properties in Western Australia. However, the producer survey undertaken in this project indicated that the majority of producers ultimately desire accuracies of <10cm for high value farm tasks such as harvesting, seeding, and spreading. This indicates that producers would be unwilling to accept SBAS signals as an alternative to COTS systems until comparable accuracies are available or the SBAS signals can value-add to their existing COTS systems (e.g. through improved reliability and less redundancy).

However, this project has demonstrated that there are considerable benefits to be accrued from using the SBAS signals for general farming tasks (e.g. livestock management) or high value tasks where the accuracy required is lower (e.g. spreading).

11. References

BadElf 2018, *Bad Elf GNSS Surveyor – Specifications*, viewed 9 December 2018, https://bad-elf.com/pages/be-gps-3300-detail

Llewellyn, R, and J Ouzman. 2014. "Adoption of Precision Agriculture-Related Practices: Status, Opportunities and the Role of Farm Advisers." *Report for Grains Research and Development Corporation*.