Choosing fit for purpose open source AgTech innovations on a large broadacre mixed farming enterprise

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1. Abstract

This is the second of a six paper series on farmer agtech adoption in the WA grains industry that use open source information technology devices to solve for production problems that increase productivity. The first five papers are case studies[2] outlining the business drivers of the adoption of differing types of AgTech adoption. A key proposition under investigation is that the particular circumstances of a farm implies that each farm will have a different path of open source information technology adoption that will give it the best risk adjusted rate of return. They consider the variables of farm scale (three are at or above minimum efficient scale[3] – MES - for cropping), enterprise mix (three are mixed farm operations), rainfall zone and management structure / depth and group vs. single farmer adoption. The sixth paper is a summary document of key themes, - including the interaction of adoption with on and off farm connectivity and data integration - and public policy implications. It will discuss private and public structural and strategic options to deal with connectivity and complexity issues that are necessary for WA agriculture to access the productivity gains possible from adopting the full suite of available technologies.

This case is similar to the first case in that: both are of a similar size (~10,000 ha); both farm on the edge of the low and medium rainfall zones; both are at least minimum efficient scale in grain production (or 'one tractor size' or 'unitisation scale'; that is a minimum of 4,000 ha); both have sufficient financial resources to deal with the cost of initial investment; and both have management structures to permit the business development needed to deal with the inherent complexity associated with adopting a new technology.

However, the Newmans' farm is a discontinuous mixed operation of grains and sheep spread over several properties. The farm places its premium on monitoring data largely pertinent to livestock production because this generates the best rate of (risk adjusted) return for it.

Typical of most WA broadacre farms, connectivity to the Newman's farm is poor. Much of the farm does not have mobile coverage or frequently drops out and the NBN satellite service is slow, intermittent and expensive. Consequently, the Newmans have invested to create an internal farm connectivity backbone onto which open source technology devices are attached to solve production problems. They have also invested in farm to mobile tower connectivity; further investment to automatically connect to the existing satellite NBN connection in case of mobile tower failure is in progress. The rate of return from these investments is high, reflecting significant productivity gains.

Modelling by Perret et al (2017) for the Cotton CRC indicates that very large productivity and Gross Value of Production gains can be made by the full adoption of decision / precision agriculture. A key issue running through these papers is how are farms able to begin the journey of adopting such technologies?

CSRIO's ADOPT framework is used to outline the observed patterns of farmer adoption of new technologies. The Newmans' adopted agtech technologies are easily trialled, easily reversed,

[1] Department of Primary Industries and Regional Development
[2] Cases one and two are complete and available.
[3]Minimum efficient scale in WA grain production is 'one tractor size' or 'unitisation scale'; that is a minimum of around 4,000 ha and a maximum of around 6,000 ha before needing additional machinery.

comparatively low cost, and because of the farm’s management structures and financial resources, they are able to be absorbed into existing production without greatly increasing complexity. The pertinent question is whether the expense and complexity of establishing this type of system implies a significant barrier to entry for farmers without the required financial resources and management structures. This theme will be further explored in subsequent case studies.

2. Paper rationale and purpose

2.1. Mixed farming operation's choice of technology driven by its needs…

This is the second paper in a series of five cases examining the productivity gains and value created from the adoption of intra (on farm) farm connectivity and related IT devices. This case study focuses on a 10,500 ha (7,500 ha arable) mixed farm consisting of 4,300 – 5,800 ha of cropping[4] (so it is of minimum efficient scale, (MES)[5]) and the balance of sheep pastures (12,000 head). The rotation is determined by rainfall, previous season's activities and relative values of products. As with the first case study, its purpose is to understand the farm's choice of technology, which is adopted to provide solutions to the highest value (most binding) constraints to its production system. A key message of this paper, is that different farming operations with differing needs will find greater value (risk lowering and or cost reductions) from configuring a package tailored to those needs. This farm has installed a mix of LoRaWAN devices and camera monitoring technology because of the risks and values created by its mixed farming operation.

2.2 Specialist grain farming operation's choice of technology driven by its needs…

Readers who are interested in a large scale (10,000 ha) specialist grains operation are directed to the first paper. The first paper examined that farm's adopted technology (WiMesh) which is highly suited to tracking operational data. While it will be used to drive machine logistical efficiency, the technology will also be used for many other purposes, such as collecting weather station data and augmenting an array of already rich data sets. A key insight of the first paper is that the particular uncertainties (that is, risk without known probabilities for practical business planning purposes) pertaining to a *specialist grain operation at the edge of a medium and low rainfall zones*, provides *high motivation* to invest in its chosen precision agriculture (PA) technologies. This outcome is notwithstanding the complexity associated with these technologies' use and the farm's previous limited (external) connectivity, which has resulted in an 'edge' (on farm) investment in connectivity, data storage and improved connectivity to the mobile network. In turn, these technologies enable significant operational cost reductions, as well as helping to address risk issues associated with a highly optimised, data driven production system.

Consequently, the first case study's farm's use of a suite of precision agricultural (PA) technologies may be thought of as closer to the 'decision agriculture' end of the IT spectrum as described by the Australian Farm Institute's report on Smart Farming (AFI, 2016). The AFI defines *decision agriculture* as 'analysis of digital farm data along with other relevant digital datasets such as soils and environmental data which leads to improved data driven decision making by farmers and enables the use of data driven technology' (p.5).

Perret et al (2017) estimated that a 25% increase in GVP (the actual production output) across agriculture if decision agriculture were fully implemented. In grains the estimated increase in GVP was 51% and its estimated productivity improvement tallied nearly 17% as indicated in Table 1:

[4] In 2018 the program consisted of 1500 ha of oats, 1300 ha of wheat, 500ha of canola and 1000ha of barley.
[5] Minimum efficient scale is the scale needed to use a set of machinery such that the average cost of that machinery does not decline very much. In WA, that is about 4,000 ha. At about 6,000 ha an additional set of machinery is needed as capacity limits are reached the existing machines.

Table 1: Productivity improvements and corresponding increase in GVP for cropping sectors

Practice	Productivity improvement modelled (%)	Increase in GVP (%)
Fallow preparation	0.98	2.98
Crop rotation	5.00	15.24
Planting	3.28	10.00
Crop nutrition	2.85	8.68
Crop protection & weed control	0.26	0.79
Labour saving	2.50	7.62
Yield forecasting	2.00	6.10
Total	**16.86**	**51.41**

Source: Perret et al (2017)

2.3. Precision agriculture's low adoption rates…

However, precision agriculture tools have not been widely adopted across WA farming systems and this perhaps unsurprising when considering their adoption using CSRIO's Adopt (Adoption and Diffusion Outcome Prediction Tool) framework. This framework 'is the first tool … to make quantitative predictions about the adoption outcomes of new farm practices' (Kuehne et al, 2017). Table 2 indicates a high predictive ability across a number of adopted farming practices and although the authors note that its predictive power is likely to be less in times of rapid change, it provides a valuable engagement and educative tool regarding adoption issues.

Table 2: Comparison of ADOPT's predictions and actual adoption estimations

Practice	Peak adoption level (%)		Time to peak adoption (yrs.)	
	Predicted	Actual	Predicted	Actual
Autosteer	83	83	15	20
Bt cotton	98	90	9	9
Lupins (WA)	72	75	14	10
Mace wheat (WA)	71	67	4	6
No till (SA)	79	83	20	22
Saltbush (SA)	9	5	23	22

(Kuehne et al, 2017)

The ADOPT framework is structured around:

a) The characteristics of an adoption practice that influence its relative advantage
   - e.g. the relative upfront cost, reversibility of the practice, profit potential, time before profit, environmental impact, time before environmental benefits, risk ease and convenience
b) The characteristics of the farm population that influences their perceptions of relative advantage
   - e.g. profit, risk and environmental orientation, scale, management time horizon and short term constraints
c) The characteristics of an adoption practice that influence its ease and speed of learning about it
   - e.g. trialling ease, complexity of implementation, observability to other farmers
d) The characteristics of the potential adopters that influence their ability to learn about the practice.

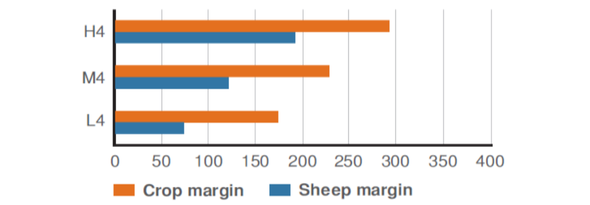
- e.g. advisory support, group involvement, relevant existing skills and knowledge and practice awareness

Precision agricultural (PA) tools are often complex and outside of the skill sets of many farmers. They also often pre-suppose infrastructure not readily available to many farmers. For instance, while the latest machinery have many inbuilt PA systems, much of this is unaffordable to many farmers. For those with access to the technology, the lack of connectivity is often a major dissuader to farmers to use the data created within their production systems. These themes will be revisited in greater detail in the discussion paper that sits over the case studies series.

2.4. Mixed farming's natural risk hedge

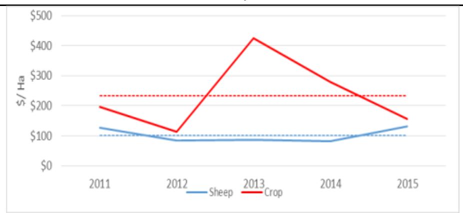
Cropping's mechanisation and associated scale economies have resulted in higher margins and its expansion in recent decades at the expense of livestock production (figure 1). However, Kingwell et al (2013) estimated that only 23% of WA growers were specialist croppers. While Planfarm estimated in 2016, that on average, its client base generated only around 18% of farm income from sheep and wool, livestock remains a traditional hedge against the vagaries of seasonal failure. This is because sheep can be fed a failed crop and thus provide all important cashflow from meat and wool; in turn this provides a powerful motivation for their retention in farming systems. Depending upon the system, other integration benefits may include increased productivity (using non arable land, labour utilisation, using low quality grain) and improved pastures and cropping (weed control and nitrogen for crops) and succession planning (Kirk and Omodei, 2017). While crop margins are more volatile than sheep margins as they are more responsive to seasonal conditions (Figure 2), sheep margins are more driven by meat and wool prices.

Figure 1: Average crop and sheep margins $ per hectare for the L4, M4 and H4 for 2011 – 15



(Kirk and Omodei, 2017)

Figure 2: Cereal sheep zone[6] enterprise gross margins. Average GM, crop $234/ha, sheep, $102/ha

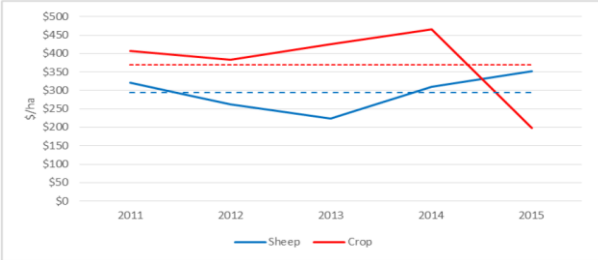


(Herbert, 2016)

Greatly improved meat and wool prices in recent years have increased returns, lessening the cost of this hedge. Indeed, Herbert (2017) projected that from 2015 onwards (Figure 3), sheep gross margins would exceed crop gross margins in the High Rainfall Zone (HRZ).

[6] Bruce Rock to Tammin

Figure 3: High rainfall zone enterprise margins. Average GM, crop $370/ha, sheep, $295/ha



(Herbert, 2016)

While significant switching costs may exist (fences, dams shearing sheds etc.) for farmers wishing to re-enter sheep, Perret et al (2017) noted that the major cost for sheep flocks is labour at around 22% of cost of production. Indeed, wool labour costs are even higher 'due to the frequency of hands on sheep management and harvesting activities' and consequently 'there is strong demand for technologies that reduce labour such as 'remote flock, pasture and water monitoring (Perret et al, 2017)[7]. That is, management complexity as well as labour costs are major constraints to sheep production and profitability.

Perret et al (2017) estimated that full adoption of decision agriculture in the sheep meat industry could generate estimated increase in GVP of 17% and 38% in cumulative productivity improvement (Table 3). Their estimated gains are similar for wool production (Table 4):

Table 3: Productivity improvements and corresponding increase in GVP for sheepmeat sectors

Practice	Productivity improvement modelled (%)	Increase in GVP (%)
Breeding decisions	13.00	5.92
Feed, landscape and water meter management	12.00	5.47
Animal health and disease monitoring	10.00	4.55
Labour saving	2.93	1.33
Total	**37.93**	**17.28**

Perret et al (2017)

Table 4: Productivity improvements and corresponding increase in GVP for wool sectors

Practice	Productivity improvement modelled (%)	Increase in GVP (%)
Breeding decisions	10.00	4.66
Feed, landscape and water meter management	10.00	4.66
Animal health and disease monitoring	10.00	4.66
Labour saving	2.99	1.39
Generic product marketing	5.00	2.33
Total	**37.99**	**17.71**

Perret et al (2017)

The above tables suggest that if sheep are a common risk mitigation tool for higher volatility cropping, then IT investment may be possible to lower risk and increase productivity at even faster rates than in the grains industry (Table 1). But which IT technologies? The ADOPT framework above suggests that technologies that can be *simply* applied (given the farm's management structures, access to advice and scope for trialling), are relatively cheap (given the farm's financial resources),

[7] Perret et al (2017) also report that only around 25% of Australian sheep businesses are Merino based. This implies that wool supply may remain relatively unresponsive to increased prices, particularly if there are high costs of switching back to sheep and particularly wool production (fences, dams shearing sheds etc.).

have very short payback periods and easily reversed may feasibly be an entry point for digital adoption for mixed farmers. Further, the digital infrastructure created for these purposes can also provide a *common platform* to apply technologies to achieve productivity and risk mitigation outcome in grain production. This is the strategy pursued by the Newman family.

The adoption of a more limited subsection of technologies by a farmer without the management structures or the financial resources of the first two case studies is the intended subject of the fourth case in this series.

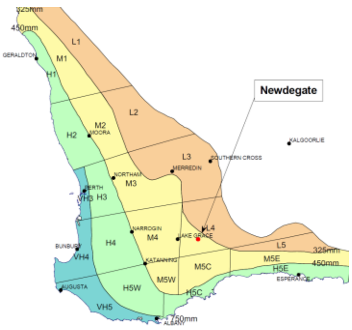
An overarching summary and discussion document will summarise the findings of the five case studies and discuss a range of possible industry and government strategies that could accelerate the adoption of digital technologies across WA agriculture.

3. **Newmans' Farm: Woodstock**

3.1 Seasonality creates business risk

Wally, Lee and son Charlie Newmans' 10,500 ha farm (operating as Woodstock) is located at about 14km from Newdegate, a WA wheatbelt town around 400km south east of Perth. The farm is located close to the boundary of medium (M4) and low (L5) rainfall zones.

Figure 4: Newdegate in relation to WA agricultural zones



The long term variability in marginal rainfall (table 5) and the area's reputation for frost events provide rationale for a mixed farming operation.

Table 5: Rainfall data, Summary statistics for all years (Newdegate Research Station, 40 kms distance)

	Mean	Lowest	5th %ile	10th %ile	Median	90th %ile	95th %ile	Highest
mm	370.0	192.6	244.5	252.2	359.8	503.4	524.7	593.4

Source: Bureau of Meteorology, n.d.

2018 was a comparatively dry year combined with frost over much of the farm and resulted in lower crop yields compared to the previous five years. These five years were some of the best that Wally and Lee had experienced in their 45 years of running the property (see table 6).

Table 6: Annual rainfall, Newdegate Research Station, 2013 – 18

Year	2013	2014	2015	2016	2017	2018
mm	330.8	398.2	353.0	476.0	411.2	230.2

Source: Bureau of Meteorology, n.d.

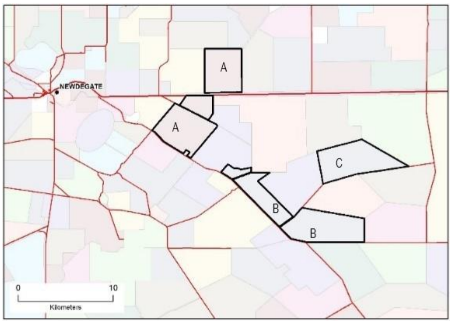
3.2. Scale via amalgamations presents challenges…

The operation is not contiguous, consisting of several discontinuous blocks (figure 5) as a result of amalgamating 6 farms since the 1930's. This reflects the pattern of industry rationalisation as machinery scale increases have driven increased machine work rates and labour substitution.

The original home block (part of 'A' in figure 5) has been in the family since first settlement in 1922. The last block added was in 2004. Further additions would be contemplated if the farm could be made more contiguous. However, these would be limited to no more than 2,000 ha as this would be the limit at which the existing set of machinery could be efficiently deployed. This implies a foreseeable limit to cost reductions from capital widening (scale). It also suggests that the farm has good reason to investigate capital deepening opportunities (investment that makes more efficient use of existing resources).

The furthest incorporated farm from the farm house is Block C, 'Trezies', which is about 16km directly and 25km by road. However, it is about 35km to the furthest reach of the farm from the farmhouse. The farm's discontinuous, large size implies that the cost of monitoring is high. Scale and discontinuity is a particularly important consideration for livestock management. For instance, sheep require access to food (mineral licks and other supplementary feed is made available in self-feeding units in paddocks) and critically water, especially in hot weather. Mobile cameras can also be very useful aids when carrying out farm operations. For instance, the farm is currently investigating using cameras to increase its co-ordination between machine operators when cleaning dams.

Figure 5: Location of the Newman family's operation spread over an amalgamation of numerous locations, organised into 3 discontiguous farming areas.



The middle block ('B'), consists in part of the 'Ranch', which is characterised by a lack of surface water due to a combination of topography and salt prevalence. However, it does contain a good underground stream so the stock watering system consists of bore, tank and an extensive network of pipes. Piped water is also necessary in other pockets around the farm for the same reasons. The small sharp rock content of soil pockets through which pipe is laid results in pipe bursts which can be difficult to find, expensive to fix and results in the loss of valuable water. Stock demand for water rises in hot weather. If sheep are without water for long enough, it can result animal health impacts. In three days breaks in the wool can begin to occur and this drops to two days in hot weather. Death can occur in three or four days or even faster in very hot weather. Ensuring stock water availability, including understanding pipe flows to locate leaks (in pipes or troughs) reduces the potential for significant losses.

Furthermore, stock are vulnerable to theft, the incidence of which has increased across the wheatbelt in recent years as stock values have improved. Machinery, equipment and fuel have also been vulnerable to increasing theft in recent years, particularly if farms are unoccupied. Police have reportedly welcomed farmers' installation of cameras on their properties as 'suspect licence plate numbers and vehicle descriptions are particularly useful to police' (Mochan, 2018).

A dedicated sheep grazing operation may configure the property in smaller paddocks to aid ease of handling. A dedicated cropper is likely to remove all fences and square large paddocks for ease of machine operation. A mixed operation must compromise by having paddocks large enough for efficient use of grain machinery and yet maintain fences and water infrastructure for stock. Locating stock, to check on their wellbeing, in a large undulating paddock with patches of bush, can result in having to conduct extensive searches, incurring labour, vehicle and time costs. This is further complicated by having to drive around planted paddocks to gates to access sheep paddocks, suggesting even potential larger savings from knowing the location of flocks.

Monitoring of sheep feeders reduces labour costs by eliminating unnecessary long drives to check levels and refill. Sensors can advise the levels of all feeders in operation, allowing better planned feed delivery.

Monitoring extends to grain production and logistics also. For instance, co-ordination costs can be reduced by providing monitor information during harvest about which field bins are how full and whether they are being filled. This would be particularly useful to truck drivers returning from CBH Newdegate.

Improved monitoring of boundary gates and fences also improves bio-security, as stray sheep can enter the property searching for food and water and bring pests and diseases with them.

Poor connectivity means that mobile phone coverage is problematic across the farm and data transfer is limited and slow. This is because it relies on connection to a Telstra tower 14km from the farm house.

Accurately monitoring soil moisture levels would help to better define inputs and management decisions, such as fertiliser and seeding rates[8].

Dams are susceptible to nutrient overloading following large rain events and stock can be risk if these levels are not monitored and understood.

3.3 *Including adding to existing management complexity …*

A mixed enterprise implies that a set of management skills are required for each enterprise in addition to generic farm business skills. That is, some gains from specialisation are given up as part of maintaining the optionality value of running both systems. On the other hand, synergies between the two production systems afford the productivity gains noted earlier in this paper. However, the point is that management capacity is always at a premium in any farming system. This is because of the large number of highly changeable variables that can impact a biological commodity production system, particularly those in open environment such as broadacre WA. This may be more so in a mixed system, especially one that is drawn out over large distances. Management structures and technologies that solve for that complexity are highly valued.

The farm's management structure consists of co-specialised roles between father Wally and son Charlie. Wally's focus is on day to day business management and strategic business development, with the balance of his remaining time used to discharge his duties as CBH Chair. The planning

[8] http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/soil-moisture-monitoring-in-dryland-cropping-areas

horizon for the farm's digital rollout was over 12 months. It consisted of research into competing technologies and suppliers' costs and capabilities, recruitment, and project design. Project management then moved onto infrastructure build (such as towers), device trialling and, currently, software development. Once the software is fully developed, new devices will be trialled.

This is made possible by Charlie assuming the role of operations manager responsible for day to day running of the farm. Charlie's operational role is also pivotal in informing the selection and design of devices to ensure that their deployment is complimentary to the day to day running of the farm.

The structure is further buttressed by the employment of a machinery specialist, as keeping all plant and equipment operational is critically important especially for cropping cycles. The farm uses a mix of new equipment (pertaining to grain) and good quality, second hand machinery (graders etc.) frequently retrofitted to incorporate technology that is available to later models (see next section). For instance the air seeder is current being upgraded to incorporate sectional control. The machinery is maintained by the farm. The farm has a number of returning well trained, peak time operators (shearers and plant operators). Staff are well cared for and given as much responsibility as they wish to assume which promotes staff engagement. Permanent staff are also engaged by providing continuous training. Permanent and casual staff turnover is consequently very low.

The farm's strategic direction set jointly by Wally, Lee and Charlie.

4. Selecting investment into technologies that reduce complexity, risk and increase productivity

4.1 Pattern of farm technology investment driven by returns, risk and complexity.

The farm's pattern of investment into technology is reflective of the earlier ADOPT framework in that it is a result of identifying investments that result in fast payback and have scope to be easily incorporated into existing management practices and / or improve operational ease. For instance, the farm was an early adopter of a computer controlled boomspray (1992) to maintain constant litres per hectare rates at variable speeds, GPS guidance (2000) for spraying and spreading, and full autosteer (2004). The GPS and guidance had 50% and over 100% rates of return respectively.

Air seeders were not adopted early as the technology was too unreliable. This changed with the introduction of press wheels and better distribution and monitoring systems. Consequently, the farm rapidly adopted air seeding as part of a general machinery upgrade in 2004.

The farm has not been proximally soil mapped[9] (using Gama spectrometry and EMI) as the marginal benefit relative to the complexity of applying the further precision agriculture tools is too low. Better connectivity and availability of decision making support tools would likely tip the equation towards considering these tools. Regular soil tests are GPS mapped.

4.2 Building a backbone from which to hang technology solutions a first priority

The farm's poor connectivity means that to address the key problems identified earlier, the first priority was creating a network of on internal farm connectivity (the 'backbone') to connect the devices needed to address them and enhanced connectivity to the mobile tower in Newdegate. The

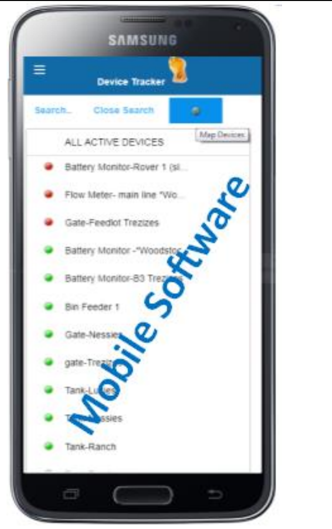
[9] *The value of these maps comes from overlaying them with yield data to identify the limiting factor to yield e.g. high acidity that limits nutrient uptake indicating a need for liming and other soil amelioration practices and the need for a specific fertiliser application.*

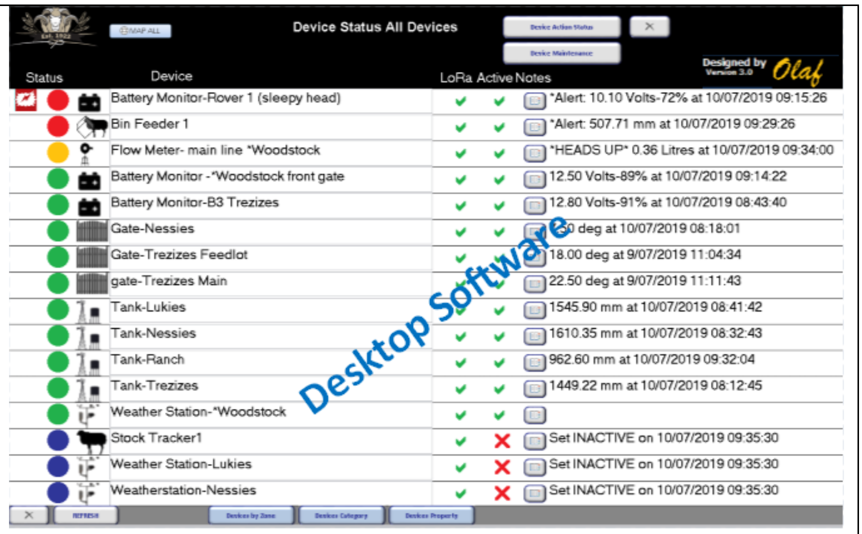
backbone consists of a server and its related software (to store data that cannot be exported to a cloud based server via the internet), towers[10] that provide line of sight for devices (such as cameras), Internet of Things (IoT) gateway devices, Point to Point antennas to connect devices to the farm's HD DVR, Internet and server, the project's design and configuration (Wally and an IT specialist), the home internet connectivity upgrade (two 4G antennas mounted on a 30m tower: 50 to 60mbs), the paddock fixed Wi-Fi (running at 2.4 MHz to the outlying base stations and 5.8 MHz form these base stations to the homestead base station) and cabling. The backbone is the cost of establishing the farm's enabling capability and any further device added is an incremental cost. The network is the equivalent of a 4G which will allow video transmission from the cameras for up to 15km. It will also connect to LoRaWAN network devices. The approximate cost of the backbone was about $47,000.

A gateway is a piece of networking hardware used in telecommunications that is 'simply an entrance point from one network to another' (Wavelink, n.d.). Therefore, a gateway mounted on a tower with line of sight to a tank monitor receives the data from the monitor and relays it to a preconfigured computer which in turn converts the signal into a readable form. From there it is displayed on the farmer's phone/computer as either on a dashboard (Figure 6) or as an alert.

Figure 6: Device Tracker Dashboard, 1

Figure 7: Device Tracker Master





LoRaWAN[11] (Long Range, Wide Area) is a networking protocol used to wirelessly connect battery operated devices. It is low powered and device batteries can last for months or years. This is because of the infrequency of data transmission and the very small data packages that are transmitted. This technology is not suited to video streaming or real time operational data streaming. It is highly suited to pre-set periodic monitoring.

A second, concurrent priority was to identify which major constraints were most amenable to a technology solution. This involved defining the problem, the selection of the most appropriate devices and a structured process to test them on farm. To date, two roundtable discussions between the farm's management, its IT advisor and its equipment supplier have addressed each of

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[10] The tallest tower at the farm house is 30m and retrofitted from the old TV aerial.
[11] https://www.loriot.io/lorawan.html
For an outline of long range, low power radio technologies go the 23 minute mark of https://hwcdn.libsyn.com/p/1/0/e/10eb41902f972652/IOT051.mp3?c_id=11299222&cs_id=11299222&expiration=1555041839&hwt=70b727078414d2100b8e657b76f2f7c7

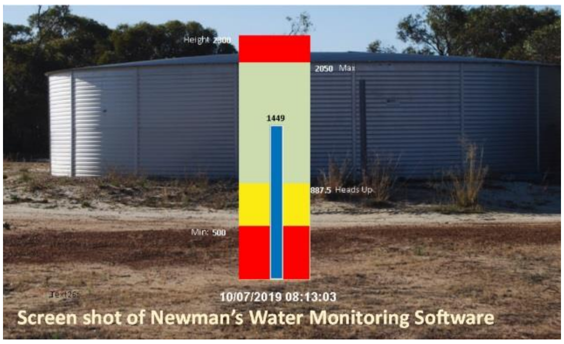
these issues. The chosen technology must address the key demands of the farmer in question and not be distracted by software or mechanical appeal. Further, it must be able to be applied as simply as possible and stand up to real world farm conditions.

As of late January 2019, trials have been carried out on vehicle trackers over the whole property, stock trackers at 3km and 17km, water level sensors at tanks at 10km (using an internal antenna) and 15km (using an external antenna) and gate monitors at 3km to 5km range. Current trials are assessing 12v battery level sensors for a camera and a water flow monitor. A planned next stage is to test weather stations recommended by Department of Primary Industry (NSW) and test a probe to monitor moisture and other soil attributes with one of the stations. If the test proves the probe's feasibility, probes will be installed on each station.

4.3 Including the creation of a generic software platform to standardise data interface and collection from successive bolt on devices

The third priority is to create a standardised database so that all device data feeds into a common data base; that is, it is integrated and able to be easily manipulated. At present, device data is often fragmented so it is difficult to match up. It is also often costly as device suppliers commonly charge for data maintenance / access via proprietary dashboards. The farm's intent is that new devices can be added to the database as required and can be controlled by the farm using the created single interface (Device Tracker, see figure 6) on phone or tablet or computer. That is, the data can be used in a highly farmer friendly fashion.

Collaboration between the farm's software and hardware providers allowed controlling software to be designed. Software code is written so that the data from each device is translated into a common SQL format (an industry standard[12]). This meant that Defined Categories are created to model what each category can do and the units of measure to be used. For instance, a water monitor may read depths and be measured in mm. The user must be able to easily change the depth reading to align with the size of the tank. So a standard water tank with a height of 2300mm may be set to send an alert if the level drops below 500mm or if it exceeds a maximum level of 2050mm (overflow). The screen shot of Newman's Trezizes tank monitor shows the parameters that may be set. A trough may be set at 30mm and an alert sent if it drops below 25mm. The farm will receive a report, or an alert, depending on how the minimum and maximum parameters are set (figure 6).



Screen shot of Newman's Water Monitoring Software

Also, maps may display, for instance, the location of tanks, feeders, troughs etc. as well as machinery and stock. Gates may be colour coded as to whether they are open or closed.

It is also intended that by taking ownership of the data, data maintenance costs are largely removed as the data is stored on the farm's server and accessed at will using the created software interface. Further, the data can be shared with whomever the farmer wishes, which may be particularly useful in understanding long term trends in the data; for instance, how salinity levels in dams are changing over time.

[12] https://en.wikipedia.org/wiki/SQL

In its simplest form, a farmer with an existing home Wi-Fi setup and this software on his phone, tablet or computer could buy a LoRaWAN device (such as a tank monitor, a gate monitor, flow monitor or a stock locator), put in the battery, turn it on, enter the parameters and be ready to use it. Each morning he would receive a report depending on what parameters he chose. To deploy it on the farm, the farmer would need a gateway and sufficient height to mount it so as to create line of sight between the device and the gateway.

5. Problem sets, solutions and estimated savings and costs

5.1 Problem 1: Theft … Technology Solution: cameras

Around 20 cameras are under installation on Woodstock at a total cost of around $34,000. These are to provide security around the farm house, its sheds and sheep, as well as monitoring the farm's bore and associated tank / trough. While many provide continuous live streaming, some are intermittent and remotely controlled or power up to stream intermittently (King, 2019). All have their own solar power source. With the exception of the main tower camera, they are overlapped so each camera is recorded by at least one other. The main tower camera has a range of over 30km. Further security is provided by appropriately placed LoRaWAN monitor devices. These devices reduce the risk of theft as the farm is alerted to presence of intruders in real time. It also increases the likelihood of prompt recovery of stolen items as perpetrators' identity can be quickly disseminated to police. The LoRaWAN device ranges have so far tested to over 15km.

If enough sufficient gateways are deployed across the farm and on other's farms, then the stolen items can be tracked whenever the stock are in gateway range. This is an example of a network effect, where the value of the investment increases as other farmers invest in this technology.

To date, establishing accurate sheep numbers make it difficult for the farm to estimate the likelihood of theft having occurred. This is because theft often occurs in small batches to reduce the likelihood of detection. Consequently, the farm is also exploring trialling the use of a camera mounted drone to generate images for a computer algorithm to count its livestock.

Accurate stock counts coupled with low cost security monitoring will establish the parameters for dimensioning the cost of theft; however the Newmans' feel that they are likely to have a hitherto undetected problem.

However, use of the drone mounted camera reduces the labour cost of stock counting, as well as increases accuracy even without the use of a counting algorithm. To count a mob of sheep in the yards or in a paddock corner takes two people about 1 hour. Capturing a drone image takes less than a minute and the sheep can be counted accurately in front of the computer by one person. Mobs are counted, on average, about 4 times a year and there are usually around 10 mobs of sheep on the farm. About 40 hours of labour is saved per annum by using this technology, or about $1,600 per year. The cost of the drone and camera was around $3,500.

Theft can also impact operational efficiency, particularly when fuel, equipment and machinery stolen at a time when a time critical operations is due. For example, the cost of a hold up in spraying, seeding or harvesting could have serious impacts on crop yields, as well as the cost of time and effort taken to secure replacement equipment. No estimation of this cost is made, but it is very much in the thinking of the farm's management.

Table 7: Comparison of savings and cost estimates from a reduction in insurance premiums due to reduced risk of theft and an increase in recovery of stolen goods.

Item	Without monitoring	With monitoring
Stock and machinery losses; operational losses	Not able to be assessed at this time	
Stock counting cost, pa	~ $3,200	~ $1,600
Combined devices, installation and contingency costs		Total: ~ $37,500

5.2 Problem 2: Stock trough, bore and tank monitoring at Ranch block… Technology Solution: cameras and LoRaWAN depth (level) sensors

Besides the main tower camera, the Ranch's tank and bore configuration has its own camera. This is to monitor the main tank's water level and whether the bore pump (windmill) is operating. There are also a set of LoRaWAN monitors on the bore, tanks and adjacent troughs. The LoRaWAN devices and the camera provide low water level alerts and a degree of redundancy in case one set of equipment fails.

The following estimates of the costs of running out of water plus the costs of monitoring provide sold reason as to the two systems' deliberate overlap.

The round trip between the farm house and tanks is about 32km. During the cooler months inspection is carried out 1 a week; during the remainder of the year it is a twice a week job. This tallies to around 92 trips a year and at $1/km implies an annual cost of around $2,950. Each trip takes about 2 hours to complete (including fence checks etc.), or about 180 hours per year. Labour is assumed to be $40/hr, implying an annual labour cost of around $7,400. The installed technology means this trip can be reduced to once a week all year, saving around $1,300 pa in vehicle costs and around $3,200 in labour costs.

About 3,000 sheep are grazed on the Ranch's block in an average year. A lack of water in the hot weather for two days can cause breaks in the wool, causing a 10% reduction in its value. Despite the twice weekly inspections, there is a 50% chance of this occurring based on precedence. This is because troughs can be damaged immediately after inspection and the water runs out over the two or three days before the next one. Assuming the sheep cut 6kg of wool on average and there is a sale price of around $23/kg for fleece wool, the annual value of wool ales from these sheep is around $410,000pa. A 50% chance of a 10% loss of $415,000 implies around $20,000 of expected cost per annum. During testing, the monitors picked up a low tank level, proving the efficacy of the system. That is, the expected loss is projected to fall to zero, saving around $14,000 pa.

During very hot weather, 10% of sheep can be expected to die if they have no water for more than 2 days. Historically, this has occurred 10% of each year on average despite the twice weekly inspections. At $100/head assumed average value, then an expected cost from stock losses are $3,000 pa. That is, the expected loss is projected to fall to zero, saving around $3,000 pa.

Table 8 Comparison of savings and cost estimates from installing bore, tank and trough monitoring at Ranch's block.

Item	Without monitoring	With monitoring	Saving
Vehicle costs:	~ $2,950	~ $1,650	~ $1,300
Labour costs:	~ $7,400	~ $4,200	~ $3,200
Wool quality cost	~ $14,000	$0	~ $14,000
Stock loss costs	~ $3,000	$0	~ $3,000
			Total: ~ $21,000 pa
Combined devices, installation, contingency and maintenance costs			Total: ~ $12,000

5.3 Problem 3: Locating stock… Technology Solution: LoRaWAN sensors

Stock are inspected around the farm to ascertain their wellbeing as well as the condition of infrastructure such as fences. Around 200km over 6 hours per week is spent locating stock around the properties. A $1/km vehicle cost and $40/hr labour cost, tallies an annual estimated stock search cost of about $23,000 pa. With 3 LoRaWAN tracking monitors applied per flock, the time taken can be reduced by around 40%, implying a new cost tally around $14,000 and a saving of around $9,000 pa.

Table 9: Comparison of savings and cost estimates from placing tracking monitors on each flock of sheep.

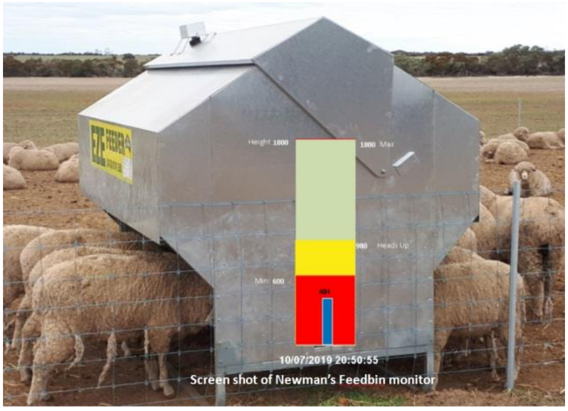
Item	Without monitoring	With monitoring	Saving
Vehicle costs:	~$10,400	~ $6,200	~ $4,200
Labour costs:	~ $12,500	~ $7,500	~ $5,000
			Total: ~ $9,200 pa
Combined devices, installation and contingency costs			Total: ~ $6,100

Trials with 'sleepy' cameras are underway. These cameras remain with the sheep in paddock and to save battery power, they 'wake up' periodically and scan the surrounding area. Should these trials prove the cameras are good enough, then further cameras will be deployed to further reduce paddock inspections.

5.4 Problem 4: Provisioning sheep feeders … Technology Solution: LoRaWAN level sensors

Table 10: Comparison of savings and cost estimates from level (depth) sensor monitors in stock feeders.

Item	Without monitoring	With monitoring	Saving
Vehicle costs:	~$7,800	~ $7,800	~ $0
Labour costs:	~ $18,700	~ $12,500	~ $6,200
			Total: ~ $6,200 pa
Combined devices, installation and contingency costs			Total: ~ $6,100 pa



Screen shot of Newman's Feedbin monitor

Stock feeders will have GPS locators and level indicators. The feeders are spread around the properties to ensure stock have access to mineral licks and other supplementary feeds necessary for optimal nutrition. The distance to complete a round trip to check and restock each feeder is about 50km. The trips take around 3 hours and are carried out 3 times per week; this is about 470 hours pa. Knowing which feeders require stocking means a better planned route and less stopping. It is thought that about 1 hour a trip can be saved, or about 310 hours pa. This implies an estimated saving of around $6,200 pa.

5.5 Problem 5: Field bin logistics … Technology Solution: LoRaWAN level sensors

The LoRaWAN devices deployed to solve this problem are the same as the ones used to monitor stock water volumes, tank levels and sheep feeders. In this case they are placed in field bins so that all relevant staff can know how full field bins are during harvest. For instance, this improves logistics for the farm manager wishing to shift bins as harvest proceeds. However, often the bottleneck during harvest is getting full grain loads through CBH Newdegate. Therefore improving grain truck loading times are likely to be the biggest cost saving from installing a device in each field bin. At an estimated 300 trips per harvest to cart around 7,500T of grain, the average return trip and loading time takes around 65 minutes. At $60 vehicle cost and $40 / hr labour cost, the total estimated cost is around $31,500. Reducing the return trip time by 5 minutes implies a saving of around $2,430 in vehicle and labour costs.

Table 11: Comparison of savings and cost estimates from level sensor monitors in field bins.

Item	Without monitoring	With monitoring	Saving
Vehicle costs:	~$19,000	~ $16,000	~ $1,400
Labour costs:	~ $12,500	~ $10,700	~ $1,000
			Total: ~ $2,400 pa
Combined devices, installation and contingency costs			Total: ~ $2,700

The LoRaWAN devices are fitted onto an existing mounted camera system of loading grain trucks from 150 tonne mother bins, which was developed by the farm in 2012. The system saves the equivalent of the cost of one full time employee over harvest. Using a tablet, the truck driver controls the tractor that drives the loading from the field bin. The driver, seated in the truck, can view the loading operation on the tablet using a mounted camera while operating the tractor's controls. The system is easy for truck drivers to use, avoids grain spills and ensures divers' safety as they remain in their truck during loading.

5.5 Problem 5: Locating pipe leaks … Technology Solution: LoRaWAN flow monitors

At the time of writing, water flow monitors had just been installed. Screenshots of the dashboard are presented in figures 7 and 8. These monitors will display water flows and spikes and troughs will indicate, for instance, the location of pipe leaks deduced from the direction of water flows. This will reduce the amount of time taken to locate pipe breaks.

Figure 7: Tank water level (Trezizes Tank)

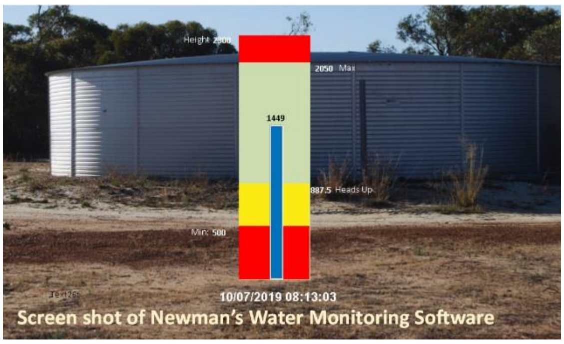
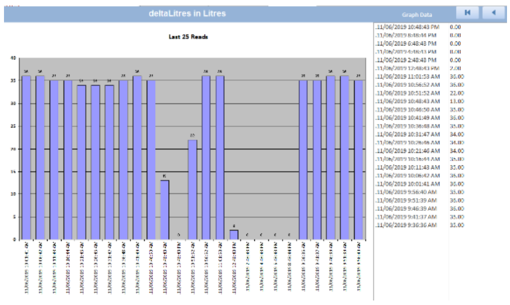


Figure 8: Mill water flow from flow monitor



The farm water pipe network is several kms and as stated earlier, susceptible to leaks because of the volume of stones in the soil and its age (installed 1969). While replacing large sections of the network is a long term objective because of the time involved in identifying and repairing leaks, the time and cost involved in replacing large sections of the network is also costly.

Table 12: Comparison of savings and cost estimates from water flow monitors on pip spurs

Item	Without monitoring	With monitoring	Saving
Labour costs:	~ $5,100	~ $2,200	~ $2,900
Combined devices, installation and contingency costs			Total: ~ $3000

Using flow monitors to reduce the time taken to identify the location of leaks has an immediate cost reduction as well as prolonging the life of the existing network. Only 5 monitors, costing $2,050 in total (plus the cost of solar power), are required to cover the entire network, as they are located on the main spurs.

Currently, in some areas, finding leaks requires that they are of sufficient size to cause green growth when the surrounding areas are dried off. Instead of checking an entire section (say 7 kms), the monitors will indicate which spur needs to be checked for a leak (say 2 or 3 kms, or a 43% reduction in time spent). Over the six dry months of the year, an average of at least around 16 days FTE is spent looking for and repairing leaks. Table 12 indicates that at $40/hr the present cost to the farm is a minimum of around $5,100 in labour costs only. The cost savings per annum are around a minimum of $2,900 for an approximate $3,000 investment.

Table 14 (over page) summarises the farm's technology development process so far.

6. Economic assessment: Net Present Value, Internal Rate of Return and Payback period of combined investment and savings

The total cost of the system described above is around $115,000. The annual net cost savings (reduced drain on cashflow) is around $40,000. The net cost savings and initial investment is discounted at 20% over a five year period. A 20% discount rate (the time value of money) implies a high opportunity cost of capital; that is, the farm has a number of valuable competing demands for capital and a high reward is required to compensate for the risk inherent in any new technology.

Table 13: Estimated Net Present Value, Internal Rate of Return and Payback of Newman farm's IT investment

		Year 1	Year 2	Year 3	Year 4	Year 5
	Benefit	$43,628	$43,628	$43,628	$43,628	$43,628
	Cost	$ 3,350	$ 3,350	$ 3,350	$ 3,350	$ 3,350
	Gross Margin	$40,278	$40,278	$40,278	$40,278	$40,278
Discount rate	20%					
NPV	$4,947					
	-$114,519	$40,278	$40,278	$40,278	$40,278	$40,278
IRR	22%					
Payback period	2.84 years					

While the life of the infrastructure and many of the devices is much longer than 5 years, a short time frame analysis is chosen in keeping with the ADOPT variables described earlier in this paper. A 2.84 year payback implies that the inherent risk of adopting new technology is appropriately accounted for.

7. Summary and discussion

Table 14 (over page) summarises Woodstock's installed, under trial and planned investment into its open source IT infrastructure. Economic analysis presented in this paper was carried out on the first six of the listed items coupled with the cost of establishing the IT backbone. The remaining list of devices are either under trial or in the planning stage as solutions to other production problems on the farm.

As the reader moves down the table it is evident that greater value can be increasingly gained from *combining* data sets to generate new insights. For instance, combining historical water nutrient level data and weather details may provide precautionary management rules to lessen the risks of nutrient overloading impacting on stock. Analysing soil moisture and temperature sensor data, combined with other data sets, should provide new insights and decision making tools for the farm in grain and pasture production. Understanding and integrating drying rates, soil moisture holding characteristics and very localised weather patterns should inform more accurate fertiliser applications, reducing costs and risks from adverse weather such as dry, heat spikes during flowering and frost damage.

Presently, small packets of LoRaWAN data can be exported from the farm via its poor connections to off farm entities, such as its device supplier. Its video stream data must be stored on farm because of the size of the files, although it can be streamed so the farm can be remotely monitored.

A key message from this study is that identifying a bundle of the farm's most pressing production constraints / risks and identifying open IT solutions – and associated infrastructure – to solve for that bundle is a sound basis to ascertain the economic merits of investing in it. The investment priorities of this case study farm are different from those of the first case study farm primarily because of the differences in production systems.

Another key message from this study is the benefits from using this technology are cumulative, easily at this early stage. That is, once the backbone is established then more technology can be hung from it to generate more useful data to solve production problems. Furthermore, integrating this data, because of its localised nature, provides increasing benefit. This provides the incentive for further investment.

Across farms, network effects also imply cumulative benefits such as the example of stock tracking made possible if other farms carry the same configured gateways to receive a signal from stock moving from these farms. The same applies to aggregating data across farms to inform, for instance, better plant breeding programs specified to localised conditions. This is feasible as the cost of gene shear technology reduces the costs of plant breeding.

More Gateways on farms introduces the use of triangulation to calculate location in place of using GPS. This would lower per unit LoRa device costs (currently $50 per GPS chip) and extend device battery life.

However, a combination of poor connectivity and the complexity of use implies a continuation of the current slow adoption rates of agtech tools. The Newmans' have solved for their connectivity issues for the time being (as more farmers coming onto existing back haul infrastructure implies eventual congestion). The complexity of these tools is amplified when coupled with managing two production systems; two production systems remains the norm for the apparent large majority of broadacre farmers in WA. This implies a more rapid take up may occur if either more mixed farms become grain specialists, and / or if solutions are found to solve for this complexity. High livestock and wool prices suggest that the switch to all grains operations may slow markedly. Providing solutions to agtech / PA complexity implies linking data sets to data innovators via fast, reliable connectivity and the adoption of standardised protocols to foster integration. It also may suggest a need for mechanisms to reduce the costs of sourcing relevant information with respect to equipment and advice. These will be key subjects of the six paper in this series.

Table 14: Newman farm technology development process to date, examples

Problem	Description	Time	Possible tech solution	Comment
1 Monitoring to warn of and record thefts	Stock, equipment and machinery costs.	Short term	On farm connectivity, long range, shed and paddock cameras; LoRaWAN gate monitors	Main reason for investigation and installation of backbone system, cameras and LoRaWAN gate monitors; gate monitors also provide bio-security control
2 Monitoring to ensure stock water availability	Vehicle and labour (travel), wool quality loss and stock loss costs	Short term	LoRaWAN acoustic devices to signal tank and trough water levels; backed up by long range camera imaging with internal connectivity	2 systems provide redundancy (reduces risk) in case of failure. Additional redundancy with LoRaWAN device configuration
3 Stock and vehicle locators	Vehicle and labour search costs	Short term	LoRaWAN GPS tracking monitor per mob to reduce search time by 40%. long range and portable paddock camera imaging. Ditto non GPS vehicles	3 devices per mob; creates redundancy (reduces risk) when coupled with planned roll out of in paddock cameras. Vehicle tracker transmits each 30s; powered by vehicle.
4 Sheep feeder provisioning	Cartage logistics when provisioning (vehicle and labour costs)	Short term	LoRaWAN devices to measure feeder levels; reduce provisioning time by x%	1 LoRaWAN device per feeder
5 Field bin volume monitoring	Cartage logistics at harvest (vehicle and labour costs)	Short term	LoRaWAN acoustic devices to indicate which field bins are full; camera for loading so driver remains in cab	All farm personnel can know field bin availability including return driver from CBH; driver can monitor loading from cab or phone
6 Water pipe repair monitoring	Search costs to locate pipe breaks	Medium term	LoRaWAN flow monitors to measure water flows.	Also provides additional stock water monitoring data.
7 Mobile hotspots	Create selective phone / data connectivity around farm	Medium term	Hotspots around towers, tanks etc. access existing fixed wireless capacity	Large data loads from machines etc. can be automatically uploaded when in range.
8 Monitor water storage quality	Nutrient overload and salinity in dams and bores	Medium to long term	LoRaWAN floating monitors to measure changes in water quality; provide alerts of nutrification risk	Data can be analysed jointly with other data to identify nutrient outbreak patterns; establish & refine trendline salinity measures.
9 Soil moisture / temperature impact on pasture and grain production[13][14]	Better refine input use to crop and pasture requirements; increase production and lessen risk.	Medium to long term	LoRaWAN moisture and temperature probes. Highly complementary to optimised grazing e.g. rotational grazing.	Create forecasting data when paired with weather station data, soil data (map & tests) and historical yields, inputs and diseases.
10 Weather stations				5 stations

[13] http://agriculture.vic.gov.au/agriculture/grains-and-other-crops/crop-production/soil-moisture-monitoring-in-dryland-cropping-areas
[14] https://www.soilmoistureprobes.com.au/about/

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