Dairy Australia

Australian Government
Department of Agriculture, Water and the Environment

RURAL R&D FOR PROFIT PROGRAM

ENHANCING THE PROFITABILITY AND PRODUCTIVITY OF LIVESTOCK FARMING THROUGH VIRTUAL HERDING TECHNOLOGY.

Final Report

Dairy Australia
July, 2016 to December, 2020
Ray King, Project Manager

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MLA MEAT & LIVESTOCK AUSTRALIA · AWI · Australian Pork · CSIRO · The University of Melbourne · The University of Sydney · TIA Tasmanian Institute of Agriculture · UNE University of New England · eShepherd Agersens

Enhancing the profitability and productivity of livestock farming through virtual herding technology.

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The Project was supported by funding from the Australian Government, Department of Agriculture, Water and the Environment as part of its Rural Research and Development for Profit Program

Contents

Plain English summary

The project *Enhancing the profitability and productivity of livestock farming through virtual herding technology,* is a partnership between the major livestock industries of dairy, beef, wool and pork, and was led by Dairy Australia in conjunction with Meat and Livestock Australia, Australian Wool Innovation and Australian Pork Limited. Research partners in the Project included; CSIRO, University of Sydney, University of Tasmania, University of New England and University of Melbourne, along with the commercial partner, Agersens, Pty Ltd.

The 4-year project that began in July, 2016 was developed to evaluate the application of virtual herding (VH) technology across different livestock production systems and examine the responses of dairy cattle, beef cattle and sheep to various cues and stimuli to improve productivity and profitability in the livestock industries.

Virtual fencing or virtual herding is an animal-friendly fencing system that enables livestock to be confined or moved without using fixed fences. By 2010, CSIRO demonstrated that cattle could be controlled using effective and ethical delivery of audio and electrical cues. In 2015, Agersens Pty Ltd licensed CSIRO IP to commercialise the virtual fencing system. The result will be the eShepherd®, a cloud-based, solar-powered, GPS-enabled virtual herding system for cattle.

Using VH technology, the project team investigated the potential to; constrain animals to certain areas for better grazing management and environmental outcomes, autonomously herd animals, or move individual or groups of animals in a herd differently to the rest of that herd. Fundamental research involving behavioural observations and physiological measurements was critical to ensure that the technology did not compromise animal welfare. In addition, the Project team has developed an understanding of the learning, management and ethical challenges faced by farmers that may implement VH on their farms.

The experiments in this Project used alternative ways to examine the potential of virtual herding in livestock systems. Pre-commercial prototypes of the eShepherd® neckbands were used in many of the experiments with beef and dairy cattle. However as the automated commercial technology had been developed only for cattle at this stage, manually operated Garmin dog training equipment was used in the sheep studies and in some of the early studies with dairy calves. In addition, a couple of the initial dairy cow studies simulated the VH technology by manually moving the fences.

Training protocols were established that enabled animals to learn the association between the audio and electrical cues so that they had learnt and correctly responded to the VH technology within several days. Various factors that may influence how the animal learns and responds to the technology were studied and these include, experience with the technology, temperament of the animal, individual variation, age and hunger. In subsequent experiments VH technology was used to herd animals, improve pasture utilisation, manage subgroups of animals and enhance environmental outcomes

The results of experiments with both cattle and sheep demonstrated that livestock were able to be moved up and down a paddock with a single backing fence. Since these experiments have been conducted, improvements in the technology should allow a quicker and more efficient herding process in cattle movement as new fences could automatically move according to animal position within the paddock.

In two experiments, VH technology was used to exclude cattle from environmentally-sensitive areas. Despite a few incursions into the exclusion zone, the results of both these studies showed that VH technology could be used to keep cattle out of specific areas within grazing paddocks with minimal labour requirements.

The application of VH technology to improve pasture utilization was examined in several experiments. In these studies with both beef and dairy cattle, the virtual fence was as effective as the electric fence in keeping the cattle within their daily pasture allocation. Furthermore, the estimated pasture consumption and productivity of the cattle did not differ between the electric-fence and the virtual fence treatments.

The results of another study in the Project demonstrated that VH technology can be used to separate small groups of dairy cows within a paddock. However there is likely to be a minimum distance that groups of animals need to be apart as social attraction in livestock appears to be a strong motivator to break through a virtual fence.

One of the principal aims of the VH project was to gather information to quantify any effects of the VH technology on physiological and behavioural indices of animal welfare to ensure the welfare of livestock is not compromised by the technology. The results of the experiments in this Project showed that VH technology had minimal behavioural and welfare impacts on livestock, while effectively containing the animals within a prescribed area. In addition the physiological and behavioural responses of livestock indicated that they were no more adversely impacted by the cues involved in VH technology stimuli than they were by other commonly encountered stimuli. The Project has identified some key practical measures of welfare assessment during the initial contact with the virtual fence, during the learning phase and during long term application of the technology.

The potential benefits of VH technology to the livestock industries were examined in case studies with dairy, beef/sheep and extensive beef production systems. The results showed that for dairy and beef production case studies, break-even costs in the range of $250 to over $400/animal were achieved for the technology. Often improved environmental outcomes were in addition to these productivity benefits.

Adoption pathways for VH technology were developed for the beef, dairy and sheep industries through a series of engagements with over 60 stakeholders across the livestock value chain as well as the establishment of a small consultative group to consider the opportunities and challenges with adopting VH technology. The adoption pathway for the beef industry aims to build capabilities in assessing and applying virtual herding technology while increasing support for adoption over time to ensure end-users make informed decisions about this innovation.

The beef industry is the initial target market for the Australian commercial developer of the technology, Agersens Pty Ltd. They will be assisting the distributor and early adopters in the northern beef industry to implement the technology on their properties. As the initial industry to be targeted is the northern beef industry, Meat and Livestock Australia will be one of the main funding sources for further extension programs for the adoption by industry. Once the technology has been established there will be further opportunity for R&D to more fully examine the application of the technology to the other livestock industries, particularly the southern beef industry and the dairy industry where there a likely to be significant productivity gains through using the technology for better pasture management and animal movement.

Virtual herding technology is in its initial stages of commercialisation as a form of automated and digitalised livestock management. In Australia, the commercial use of this technology is presently permitted only in Queensland and Tasmania. Changing state regulations to allow the commercial use of this technology is critical for the adoption of this technology and is continuing to being explored in other States, but may require further support by industry.

Abbreviations and glossary

AEEC	Animal Experimentation Ethics Committee
Agersens	Agersens Pty Ltd, commercial owners and developers of eShepherd®
CSIRO	Commonwealth Scientific and Industrial Research Organisation
eShepherd®	Agersens's proprietary name for the virtual herding technology
PTA	Participatory Technology Assessment
RSPCA	Royal Society for the Prevention of Cruelty to Animals
TIA	Tasmanian Institute of Agriculture
UNE	University of New England
UTAS	University of Tasmania
VH technology	Virtual Herding technology

1 Project rationale and objectives

Electric fencing for allocation of pasture to livestock has been used for many years, but in many livestock industries, particularly the more extensive grazing systems, it is rarely used because of labour, costs and other difficulties associated with managing temporary fences on these farms.

About 15 years ago, CSIRO started to examine the potential of virtual fencing for the northern beef industry. Using a GPS system to define fence boundaries and a specially designed neckband that alerts the animal to the fact that it has reached the virtual fence, a prototype of the system was successfully demonstrated with beef cattle.

The completely wireless system works by emitting a sound when the animal wearing the neckband approaches the boundary. If an animal decides to go past the line it receives a small electric pulse. This enables animals to learn where the virtual fence line is by associating the audio signal with an approaching boundary. CSIRO licensed the technology to Agersens Pty Ltd who began developing an experimental prototype of the technology just prior to the start of this Project.

The objective of this project was to use the pre-commercial prototypes to evaluate the on-farm application of virtual herding technology, demonstrate its implementation, and quantify and extend its benefits across the major livestock industries in Australia. Specifically, the Project investigated the potential to constrain animals to certain areas (better grazing management and environmental outcomes), autonomously herd animals, or move and manage groups of animals in a herd differently to the rest of that herd. Fundamental research involving behavioural observations and physiological measurements was also a large part of the Project and was critical to ensure that the technology did not compromise animal welfare.

2 Method and project locations

The Project was conducted across a number of experimental and commercial sites across Australia (Table 1). At these sites, well designed experiments were conducted with beef cattle, dairy cattle and sheep. For the cattle studies, a pre-commercial prototype of the automated eShepherd neckband system was used, while for the sheep studies a modified dog collar was used to manually deliver the audio and electrical cues. These animal studies were designed to:

- Optimise the cues and controls necessary for the most efficient use of virtual herding technology to control animal movement in line with acceptable welfare outcomes for cattle and sheep.
- Improve pasture utilisation and productivity through regular movement and restriction of cattle and sheep in a grazing situation.
- Determine how virtual herding can be applied to move or herd animals with the technology.
- Determine if the technology could control groups of animals within the same herd, by separating them or moving them differently to the rest of the herd.
- Develop a suitable training program to ensure all animals learnt the association between the audio and electrical cues so that the livestock consistently respond to the cues without adversely affecting animal welfare.

In addition, focus group workshops were held with the various sectors of the livestock supply chain to develop appropriate adoption pathways for the technology. Furthermore, detailed case studies were conducted on commercial dairy, beef cattle and mixed livestock/cropping farms to determine the risks, costs and benefits of implementing the technology on these types of farms.

The research findings from the animal studies in this Project may be potentially applied across the cattle industries throughout Australia, but have more immediate application to the more extensive beef cattle industry in northern Australia. The eShepherd® system should be available commercially in 2021 and the initial target market is the northern beef industry where tight control of animal movement is not as critical as in the more intensive grazing systems and the potential for productivity gains and environmental outcomes are probably greater. In addition, the technology is presently only able to be used commercially in Queensland and Tasmania as its use in other States of Australia is presently limited to experimental studies under the control of the appropriate Animal Ethic Committee in those States.

The principles of virtual herding technology have been demonstrated for the sheep industries by using a manual system with small numbers of animals in this Project, but much further development of a cost effective, automated system of delivering the respective cues to sheep will be required before it is used in the wool and meat sheep industries.

While the technology has been developed in Australia and the results from this Project have direct application to the livestock industries in Australia, the technology could be applied to extensive livestock production in other parts of the world.

Table 1: *Location of all project activities*

Name & type of site (field site, laboratory, project partner sites)	Street Address	State	Postcode
Sydney University Farms, Camden. Field site for animal trials and project partner R&D laboratory and offices	335 Werombi Road, Camden	New South Wales	2570
Tasmanian Institute of Agriculture Dairy Centre, Elliot. Field site for animal trials and project partner R&D laboratory and offices	Nunns Road, Elliott	Tasmania	7352
CSIRO Armidale site. Field site for CSIRO and UNE animal trials and CSIRO R&D laboratory and offices.	New England Highway, Armidale	New South Wales	2350
University of New England, research partner R&D offices.	University of New England, Armidale	New South Wales	2350
The University of Melbourne, Rural Innovation Research Group laboratories and offices.	780 Elizabeth Street, The University of Melbourne.	Victoria	3010
Commercial beef cattle property in NSW	Tumbarumba	New South Wales	2653
Commercial beef cattle farm in Barossa Valley, SA	1780 Jutland Road, Eden Valley	South Australia	5235

3 Project achievements

Subprogram 1: Optimising the animal response to virtual herding technology.

This subprogram was led by Dr Dana Campbell and the CSIRO team at Armidale, NSW and investigated the response of beef cows to VH cues and controls, as well how the cattle may respond to moving and complex virtual fences. In addition, they examined the use of VH technology to herd or move animals around the farm. The key results from this subprogram included:

Response to VH cues and controls

Virtual fencing is an animal-friendly fencing system that enables livestock to be confined or moved without using fixed fences. CSIRO first conducted studies in virtual herding in the early 2000's. From these studies, they developed and patented a "virtual fencing" algorithm, based on animal behaviour, learning and welfare principles. Refined through years of CSIRO's evidence-based research and development, the virtual herding technology trains livestock to recognise and stay within virtual boundaries by detecting and responding to animal behaviour

In initial studies in the Project, automated neckbands that provided audio and electrical cues to cattle were tested on naïve beef heifers to determine the specifications of these cues that were necessary to deter them from a feed attractant on the other side of a virtual fence, without compromising animal welfare

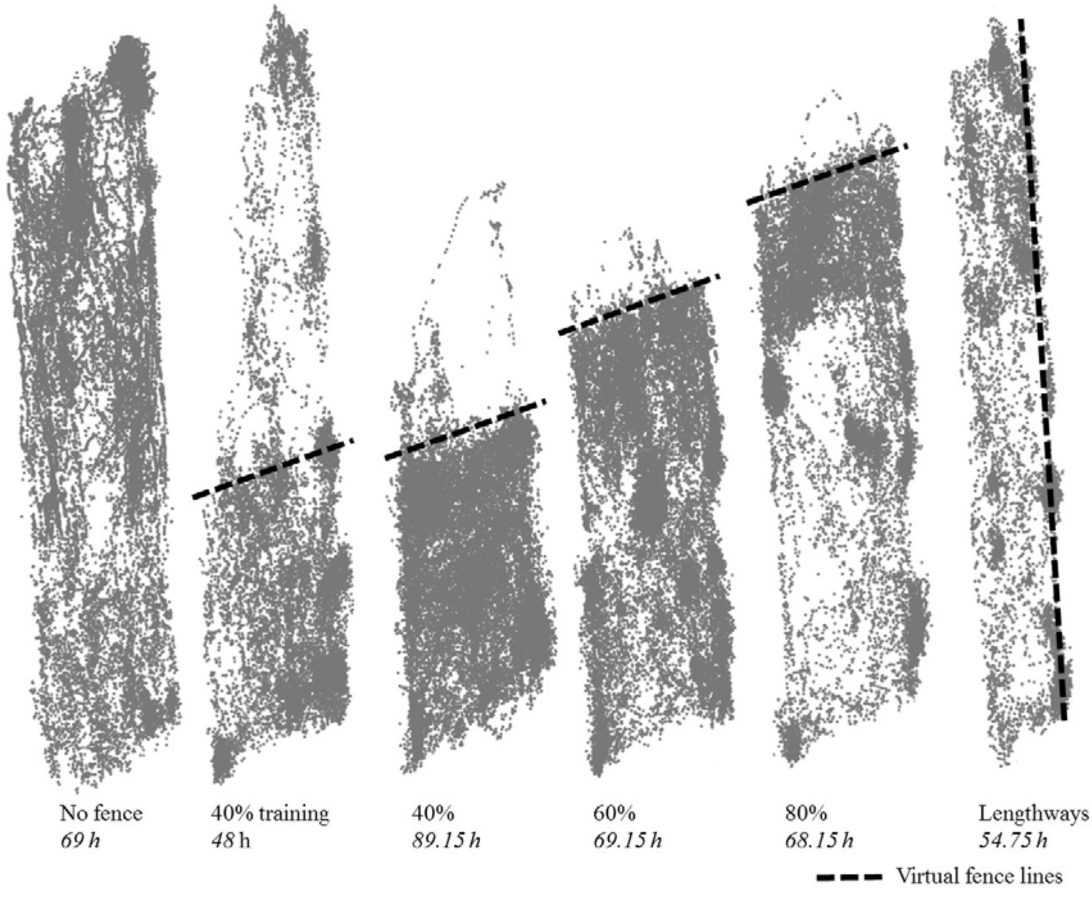
As the animal approached the virtual fence line the neckband emitted an audio cue. If the animal stopped or turned away no further cues were emitted, but if the animal continued forward an electrical pulse was applied immediately following the audio cue. The sequence of stimuli (non-aversive audio cue followed by a pulse) is predictable and the animal quickly learns to avoid the pulse by responding to the audio cue alone. The strength and duration of these two cues has now been established from these types of initial studies and were incorporated into the pre-commercial prototype for subsequent studies in the Project, as well as being used as the basis of delivering the cues from the commercial neckband. In subsequent animal studies, the automated virtual herding neckbands delivered appropriate cues to the cattle and associated with increasing numbers of interactions with the virtual fence line, cattle learned to respond to the audio cue alone.

Response to moving and complex virtual fences

An initial experiment was conducted by the CSIRO team to investigate how animals respond to virtual fence lines that periodically move. Six heifers were placed into a 6 hectare paddock and fitted with the pre-commercial prototype of automated neckbands developed by Agersens. After about a week of adjusting to the entire paddock area, animals were excluded from 60% of the paddock by a single virtual fence line across its width. After about 5 days the fence line was then moved to exclude animals from 40%, and then 3 days later, 20% of the paddock area. Finally, the line was switched lengthways down the paddock to exclude animals from 50% of the paddock area along one side.

With all the new fence lines, the animals were successfully excluded from the specified area. For the majority of time, animals were excluded from the specific areas by responding to the audio cue alone and thus the animals avoided the electrical stimuli. These results are shown in Figure 1 below and indicate a very positive response for farmers that wish to implement short-term temporary fences.

Figure 1: *Location of cattle, at the beginning of the Experiment (first "map" on the left), when they were restricted to 40% of the paddock during the training period of 48 hrs, and then the location of cattle over the subsequent 3 or so days after the virtual fence was shifted to allow the cattle access to 40%, 60% and 80% of the paddock and then finally after shifting the fenceline longitudinally down the paddock.*



Use of VH technology to institute moving and complex virtual fences to improve environmental outcomes:

The CSIRO team used pre-commercial prototypes of the eShepherd® virtual fencing system to assess how cattle may respond to moving and complex virtual fences by applying the technology to exclude cattle from an environmentally-sensitive area.

The trial was conducted on a commercial property in Eden Valley, SA, where 20 Santa Gertrudis heifers were put into a 14 hectare paddock containing a regenerative planting of native saplings. The cattle were initially trained to a straight fence line (indicated by the blue line in Figure 2) placed in front of the trees but over the first two weeks this was modified to successive contoured fences fitted around the sapling plantation (Figure 2).

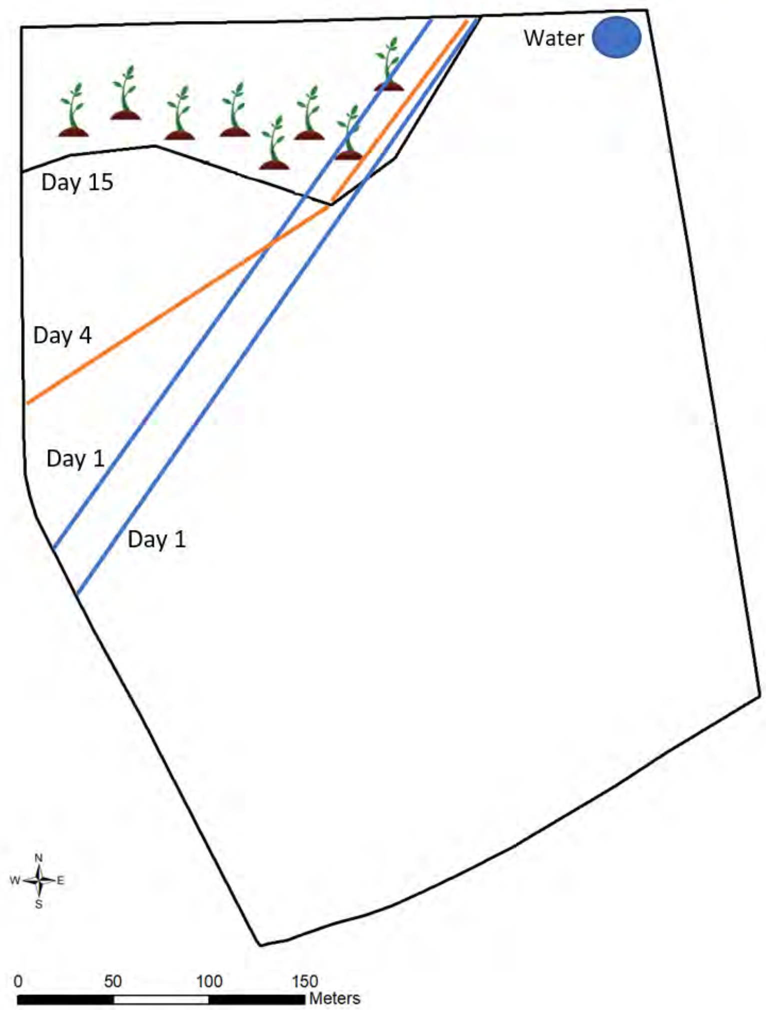


Figure 2: *Map of the commercial paddock at Eden Valley showing the succession of fence lines protecting regenerative saplings that were presented to the animals across the days of the trial.*

GPS movement patterns showed that the virtual line successfully prevented animals from accessing the saplings for the 5 weeks of the study (Figure 3). The results demonstrated that the cattle were able to rapidly learn the virtual fencing cues, respond primarily to the audio cue alone, and were excluded from the regenerating area for the majority of the trial period when more complex fence lines were imposed. Furthermore, the feed available in the protected zone at the end of the study was double the quantity and quality of the grazed zone.

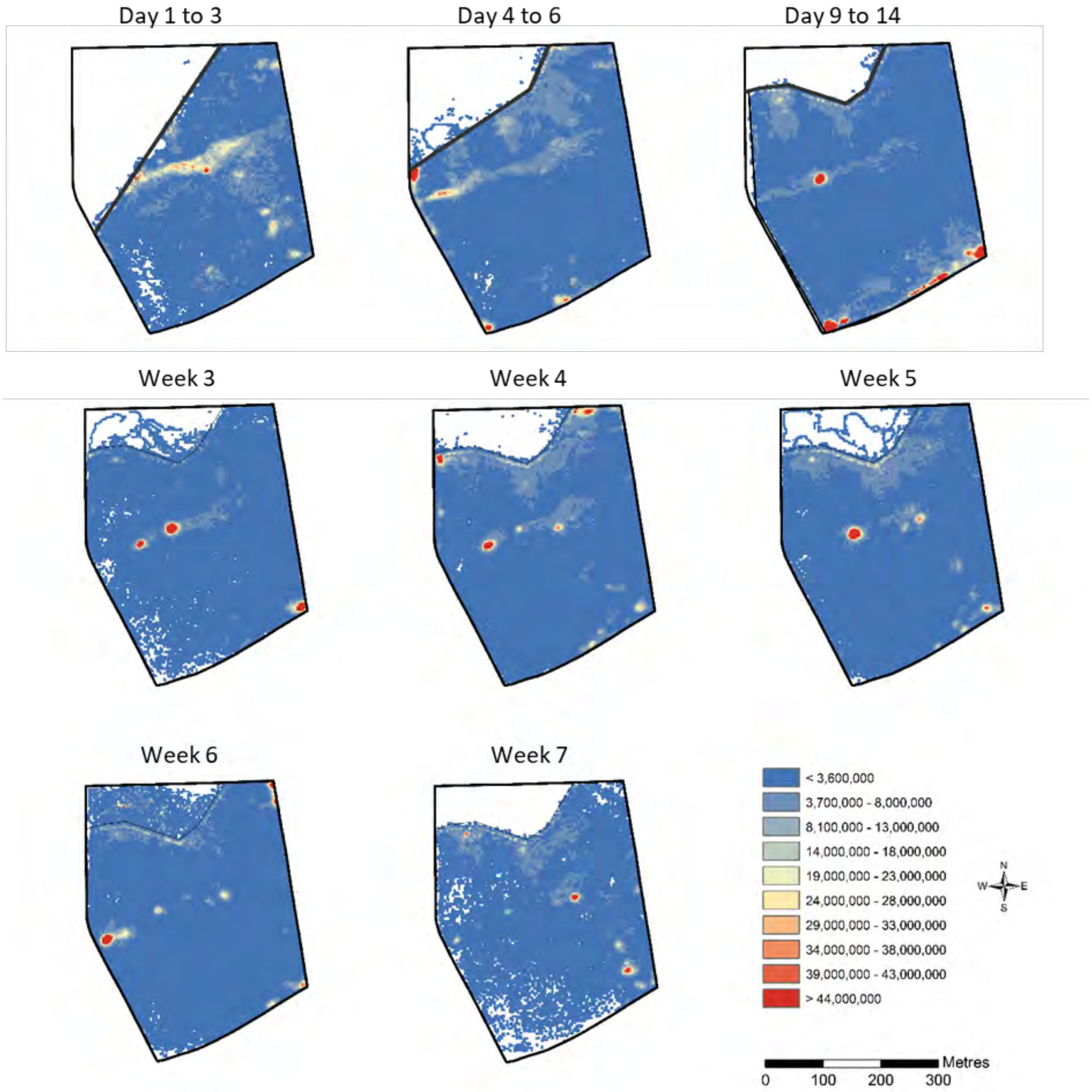


Figure 3: *The per day GPS plots of animal occupancy within the test paddock across time with progressive iterations of the virtual fence line. The frequency of GPS points of each grid was divided by the number of days for a specific map to provide the average per day pattern.*

The results of this study showed that cattle can respond to moving and complex virtual fences and application of the technology was shown to protect an environmental asset within a paddock from cattle grazing in the presence of a large feed differential.

The use of VH technology to herd or move animals around the farm

Livestock are shifted from one paddock to another and are also regularly brought into a central area for milking, mustering, shearing, etc. This may be an appreciable cost that requires labour, quad bikes, dogs or horses, depending upon the livestock industry. In addition to the costs of labour involved, moving livestock can potentially be stressful for the animals and increase animal health costs.

There are many potential applications of VH technology to herd animals in the livestock industries but most are yet to be proven. However the Project was able to demonstrate that cattle could be moved down a paddock where a back fence regularly shifts closer to the target area, thereby "herding the animals".

A 5-week trial was conducted on site at CSIRO in Armidale in 2018 to determine if VH technology could move groups of 12 beef cattle, trained to the virtual herding technology, from one end of a paddock to another through applying two different combinations of fences.

Design 1. A single shifting fence behind the group of animals to prevent them turning back.

Design 2. A fence both behind and in front of the group to keep the group together more tightly as they moved down the paddock.

The most successful design was the single fence that moved behind the group as they grazed down the paddock. Animals were herded at their own pace so sometimes it was rapid (i.e. if animals were walking), but on other occasions it was slow if they were spending time grazing. General behavioural observations indicated the animals were not overtly stressed or aroused by this design. Where the animals only had a backing fence (Design 1) Groups 4 and 5 only took around 15 min for all animals to travel down the 300 m paddock, and up to about 30 minutes for most animals to return back up the paddock (Figure 4). Although it was beneficial to have the group kept tightly together with both the front and back fences (Design 2), animals in Group 3 took over 1 ½ hr to travel down the paddock and over 4 hrs to return back up the paddock (Figure 4). The speed of movement was markedly reduced in Design 2 because the animals were getting signals from both the back and front directions.

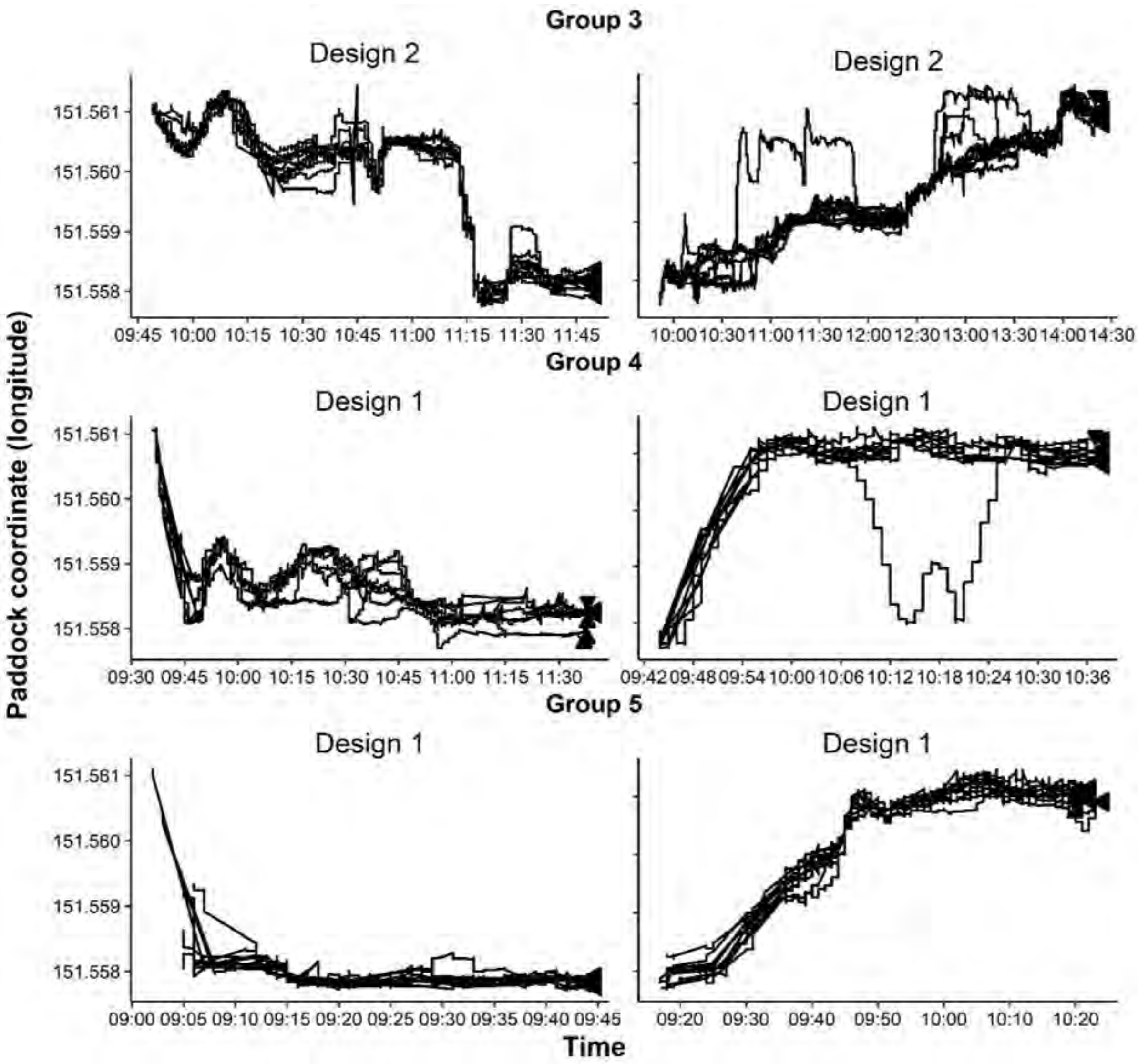


Figure 4: *Some examples of the group movement across time with different herding designs. Design 1 was simply a backing fence while Design 2 consisted of a back fence and a front fence. These plots show lines for each animal down the paddock over time (on left) and then return up the paddock (on right).*

Since this experiment has been conducted, improvements in the speed of connectivity between the devices, base station, and user-interface will minimise the variation between individuals with updating a specific new fence that is moving during herding. Thus, a front and back fence may become a viable option for moving cattle around a farm. Fences that automatically update based on animal position within the paddock may also be possible (herding fences were manually activated in the research trials).

Virtual fencing versus electric tape fencing

The team at CSIRO conducted a final trial in the Project to compare the effectiveness of virtual fencing (established with the pre-commercial prototype of the eShepherd® system) versus electric tape fencing. Eight paddocks were established on site at CSIRO in Armidale to contain 8 Angus steers each. The eight paddocks had either a single virtual fence line or a single electric tape line placed to exclude the cattle from one section of the paddock for a period of 4 weeks.

The results showed that:

- Some steers did break through the virtual fence line within the first few days while they were learning the association between the audio and electrical signals. However after this initial period, GPS location data showed that both types of fences contained the animals.
- Measurements of standing and lying behavioural patterns via automated devices attached to each steer's leg showed minimal differences between animals exposed to the two types of fences.
- Analyses of faecal samples for stress hormones showed no differences in stress responses towards the different fence types.
- All animals were able to learn to respond to the audio cue alone with more audio cues received than electrical pulses (Figure 5), although there was individual variation in their learning.

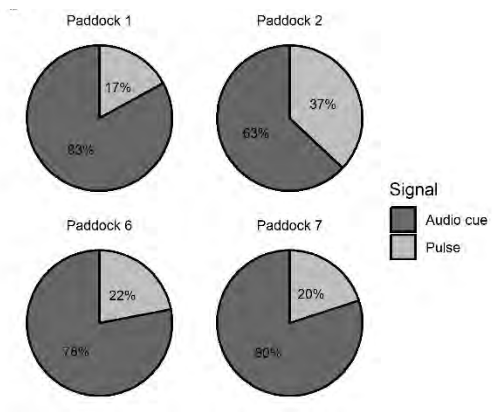


Figure 5: *The relative percentages of audio cues and electrical pulses for the four weeks in each of the four paddocks that had a virtual fence.*

These results indicate that virtual fencing technology can effectively contain animals in a prescribed area with no significant behavioural and welfare impacts being detected in this study.

Subprogram 2: Determine best livestock and pasture management for intensive dairy through more controlled pasture allocation

This subprogram was led by Dr Megan Verdon, University of Tasmania and the Tasmanian Institute of Agriculture Dairy Team at Burnie, Tasmania and investigated how VH technology may be used to strategically alter pasture allocation in intensive grazing systems to improve pasture utilisation.

Pasture is the cheapest and easiest way of feeding cattle. Maximising the proportion of fresh pasture in the diet of cattle is a key driver of profit and resilience in pasture-based livestock production systems. In Australia, the dairy industry achieves at least 65-70% of grown pasture utilised compared to only 30-40% of pasture being utilised in the beef industry. Intensive and targeted grazing management practices enable a more consistent and efficient utilisation of pasture which improves productivity per hectare while reducing feeding costs.

This subprogram investigated the potential ways that VH technology could be applied to better control grazing management and increase pasture utilisation through providing fresh pasture in more frequent allocations, cell grazing and providing fresh pasture to livestock when they are more likely to graze. In addition the Dairy Science Group examined some of the factors that may affect the response to VH technology. The key results from this subprogram included:

Factors affecting the response to VH technology:

The results of early research in this Project revealed variation between individual cattle in the learning of the association between audio and electrical stimuli which is essential to successful virtual fencing. A better understanding of factors that can influence this associative learning may ensure all animals adapt in systems that utilise virtual fencing technology.

Effect of animal experience with electric fencing:

Using manually operated collars, the UTAS team investigated the effects of prior experiences and of temperament on associative learning of the different cues in dairy heifers. Thirty heifers were reared to 6 months of age with or without exposure to electric fencing. The pairing of audio and electrical stimuli was then assessed in a feed attractant trial using manual training collars.

Heifers with experience of electric fencing showed more rapid learning of the association between audio and electrical stimuli than those heifers that had no exposure to electric fencing during rearing The more interactions a heifer had with the electric fence during the treatment period, the lower the proportion of electrical stimuli she received during training. Experience and interactions with electric fencing are associated with the day-to-day management of cattle in intensive pastoral systems. This may prime dairy cattle to more rapidly accept virtual fencing technology.

Effect of age of exposure to VH technology on the ability to learn the association between the two cues:

The UTAS group also examined the effects of age at first introduction to the VH technology on the efficiency with which dairy heifers learn the audio/electrical cue/behaviour association, as well as retention of that association long term. The experiment obtained cross-sectional data by first exposing heifers to VH technology at a given age (6, 9, 12 or 20 months of age), and longitudinal data by re-testing previously exposed heifers at 20 months of age.

The results of this experiment showed that the heifers learnt the virtual fencing technology better as they became older. It is recommended that replacement heifers should be trained to virtual fencing technology at an older age (i.e., 20-22 months of age) and before they enter the milking herd, rather than a younger age (< 12-months).

Use of virtual herding technology to increase pasture utilisation.

VH Simulation study with replacement dairy heifers:

An experiment conducted at the Tasmanian Institute of Agriculture, Burnie used physical fences to compare providing 21 month old pregnant heifers access to fresh pasture each day with fences that were moved only twice each week. Providing the heifers with fresh pasture each day increased their live weight gain by 8kg over a 12-week period and improved pasture re-growth compared to providing access to fresh pasture twice weekly. Furthermore the daily moved heifers spent more time ruminating and less time feeding, although there was no difference in pasture consumption. The heifers that experienced a more intensive grazing regime may also adapt more quickly to the intensive grazing systems when they join the milking herd.

VH Simulations study with lactating cows:

The team at UTAS investigated whether frequently offering fresh pasture to dairy cows would stimulate feeding behavior, increasing pasture intake and milk yield. Cows received their daily pasture allocation in two equal grazings while cows in the experimental herd received the same daily pasture allocation over seven smaller grazings. The fences were physically moved at these times to simulate the possibilities of VH technology. However, the results of this experiment showed that frequently feeding dairy cows fresh pasture had no effect on time spent feeding or pasture consumption, but reduced the time ruminating and milk production. The extreme grazing regime utilized in this study may have disrupted the natural grazing-rumination cycle of cows with negative consequences on milk production. There still may be potential for VH technology to be used to allow more frequent access to pasture allocation during the day that coincides with the natural grazing pattern for lactating cows.

Comparison of electric fencing with virtual fencing for lactating cows:

A large and comprehensive experiment using the pre-commercial prototype system of eShepherd, was conducted to compare the efficacy of virtual fencing compared to traditional electric fencing in allocating pasture to lactating dairy cattle. In the first study with dairy cows, the animals were grazed for 10 days using an electrified strip-fence, followed by 3 days of training to the virtual fence technology, and then 10 days of grazing using a virtual front-fence (Figure 6).

Figure 6. *Dairy cattle grazing at the virtual front-fence*

The ratio of audio:electrical cues remained above the minimum level of 0.80 while grazing with the virtual fence. This observation indicates that cows quickly learnt the association between audio and electrical cues in the VH technology and were able to apply these learnings to applied grazing conditions.

The virtual front-fence was as effective as the electric front-fence in keeping the cows within their allocation (see Figure 7) and GPS data suggest that the cows had adapted to the virtual fence within 4 days.

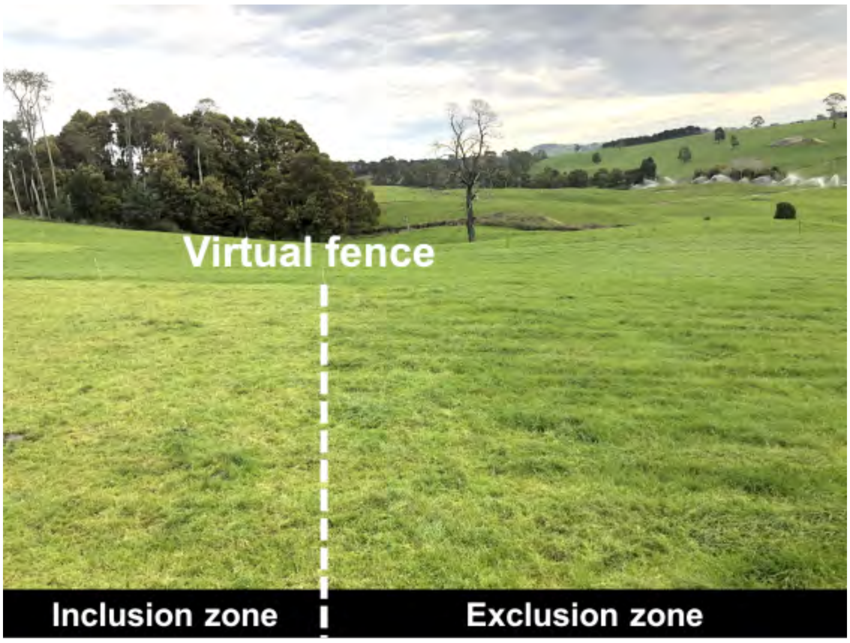


Figure 7. *Pasture depletion at the virtual fence. 'Inclusion zone' refers to the area where cows could move freely. Stimuli were delivered when cows crossed the virtual fence to enter the 'exclusion zone'.*

The milk production and live weight of cows did not differ between the electric-fence and the virtual-fence treatments, but the estimated pasture consumed was greater with an electric fence (Table 2).

Table 2. *Effects of fencing on production and behavioural responses in lactating cows.*

Measure	Electric fence	Virtual fence
Milk yield (kg/day)	25.6 ± 3.3	26.5 ± 3.5
Estimated pasture consumed (kg DM/cow/day)	13.1 ± 2.2	11.7 ± 2.8
Rumination (% of time in paddock)	33.4 ± 3.8	38.3 ± 4.5
Grazing time (% of time in paddock)	34.8 ± 4.9	28.2 ± 4.6

While cows appeared to avoid grazing near the virtual fence for 6 to 12 hours after entering the paddock in the first few days with a virtual fence, grazing behaviour soon became evenly distributed along the length of the paddock over the 24 h allocation (Figure 8). This is in alignment with data indicating that pasture depletion was evenly distributed across the paddock in both treatment periods.

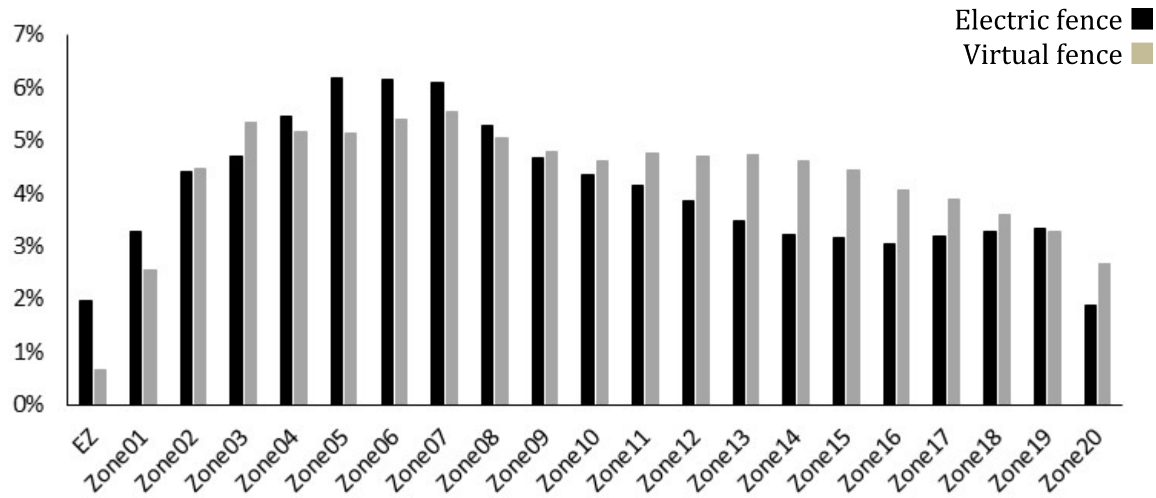


Figure 8. *From GPS records, the average percentage of time per day that cows were recorded in the exclusion zone (EZ) and in each twentieth of the paddock (Zone01 being closest to the front-fence) during 10 days of grazing with an electric front-fence (black) and 10 days of grazing with a virtual front-fence (grey).*

<u>Comparison of an electric fence with a virtual fence using automated VH technology to constrain beef cattle:</u>

An experiment conducted by UTAS examined modifying paddock layout for intensively grazed beef cattle. In this study, Angus heifers were kept in grazing cells by either, back and front electric or virtual fences. The pasture allocation provided about 10 kg DM of pasture each day to each heifer. There was no significant difference in pasture consumed or liveweight increase over the first 14 days (Table 3). Moreover, some of the groups of heifers interacted with the virtual fence more than others and often moved into the exclusion zone indicating social differences in the response in some groups of animals.

Table 3: *Comparison between an electric fence and a virtual fence on the productivity of beef heifers.*

Parameter	**Electric**	**VF**	**P-value**
Estimated kg DM offered/heifer/day	9.9 ± 0.9	9.8 ± 1.3	NS
Estimated kg DM consumed/heifer/day	7.0 ± 0.5	7.2 ± 0.8	NS
Start weight (kg)	439 ± 46.8	446 ± 37.6	NS
End weight (kg)	446 ± 42.2	459 ± 35.4	NS
Weight change over 14 days (kg)	6.5 ± 10	12.4 ± 6.8	NS

Subprogram 3: Determine best sub-herd animal management for dairy and beef.

This subprogram, led by Dr Sabrina Lomax and the University of Sydney team at Camden, NSW, developed training programs for animals to learn to respond effectively to the cues and controls, studied some of the factors affecting the response of cattle to VH technology and also examined moving groups of animals in a herd differently to the rest of that herd. The key results from this subprogram included:

Factors affecting the response of cattle to VH technology

This subprogram conducted a number of experiments that examined suitable training programs to learn the association between the audio and electrical cues. In association with Agersens, the University of Sydney have developed training programs for training cattle to learn the association between the audio cues and the electrical pulse so that all animals learn to remain behind the virtual fence, without compromising animal welfare. These training programs enable most animals to learn the association between the cues within 4-5 interactions with the virtual fence so that soon after this initial training period of 3-4 days the ratio of audio to total audio and electrical cues often approaches 90%. A minimum level of 80% once animals are trained, may be considered as a target for acceptable animal welfare.

Subsequently, the University of Sydney team examined the role of individuals or groups and hunger and satiation had on the response of cows to VH technology.

Group/individual and response to VH technology

An initial experiment assessed the learning and behavioural response of cows trained to VH cues individually or in groups. Twenty-four Holstein-Friesian dry cows were fitted with experimental prototypes of the Agersen's eShepherd® neckbands. Cows were trained as individuals or in groups of 6 to access a feed attractant of lucerne cubes at the end of a 100m paddock. A virtual fence was then set halfway down the paddock, and cow learning and response to the VF cues was tested either individually or in groups. After daily tests on 4 consecutive days, treatments were crossed over, so that individuals were then tested in groups, and the groups as individuals. An additional two tests were conducted after the crossover.

At the end of the initial training period of 4 tests, less than 10% of the animals, whether they were trained in groups or as individuals, had reached the feed attractant at the end of the paddock. There was a significant interaction between crossover and training treatment, with 20% of cows trained in groups, reaching the feed when crossed over to individuals, as compared to only 4% when individuals were crossed over to groups (Table 4). While there was a clear effect of learning, this result indicates that not all cattle may interact with the VF sufficiently in a group setting to reinforce the association of the paired cues.

Treatment	pre-crossover	post crossover
Group	0.63[a]	0.04[b]
Individual	0.41[c]	0.20[b]
P-value	0.04	

Table 4: *Probability of cows reaching feed pre-and post- crossover. [abc] values differ significantly at P<0.05.*

This result has implications for training. Due to the impracticality of training every animal on its own, a more robust group training protocol will be required. This may involve extending the training period and with minimal pressure, to provide all animals the opportunity to equally interact with the virtual fence and establish adequate learning. Training protocols for animals in large groups in the practical and commercial situations will be established by Agersens.

Role of hunger on the response to VH technology:

In an initial experiment where the effect of hunger was studied in an artificial situation, there was a clear effect of hunger, with cows fed a restricted ration more likely to cross the virtual fence to reach the feed reward. The University of Sydney team have continued the research into the influence of hunger on the cow's response to VH technology by using a more practical and common strip grazing scenario.

For this more practical experiment, twelve dry dairy cows were strip-grazed as a group for 10 days using a virtual fence, whereby the fence was moved daily to offer a fresh allocation. However on days 5 and 10 the fence was not moved, whereby cows were held off the fresh allocation, and left to graze the residual pasture in the previous day's allocation, to mimic the effect of hunger (Figure 9).

Cows had more interactions with the virtual fence on the "held off" days compared to the days when cows received a daily fresh allocation and, furthermore, the cows spent more time in the exclusion zones during "held off" days. These results indicate that if animals are hungry, they may place more pressure on the virtual fence and are more likely to move over into the exclusion zone. Cows that received the fresh pasture allocation each day remained mostly within the inclusion zone, indicating that the VH cues were sufficient to maintain the cows within a pasture allocation as a group. It was also evident from this experiment that there is a social element to cow interactions with a virtual fence, where individuals were observed responding to herd mate's behaviour.

Figure 9 *Cows graze the residual pasture when held off from a fresh pasture allocation.*

How VH technology may be used to keep separate groups of animals within the same herd.

Virtual herding technology has potential for animal containment and moving towards separating and containing multiple subgroups of animals within the same paddock. There is considerable opportunity to use the technology to separate groups of animals within a larger herd to enable better reproductive and grazing management. However, animals tend to group together naturally and it was important to understand how group dynamics and social motivation will impact on the response of animals to the use of virtual herding technology to keep groups of animals separate from other groups.

An experiment was conducted to evaluate the ability of the VH technology to keep two groups of dairy cows separated <u>within</u> the same paddock. Twenty-four dry cows were trained to the VH stimuli over 6 days. Cows were divided into two groups of 12 cows each, based on social hierarchy, whereby there was an equal representation of dominance within each group.

A 1ha paddock of irrigated kikuyu pasture was divided into five daily allocations at each end of the paddock, with a 20m buffer zone of pasture in the middle. The two groups were allocated to opposite ends of the paddock (~150m separation). Progressively over the next 5 days, the virtual fence was moved daily by about 20 metres to allocate more pasture so that the cows at either end became closer to the cows at the other end of the paddock (Figure 10). When the distance between the two groups had been reduced to about 30 metres, two cows from each group of 12 cows crossed over to the other group and did not return.

While VH technology can be used to separate groups of cows in a paddock, the results of this study indicate that a minimum distance of >50m is required to keep dairy cattle within their groups and away from other cows or groups of cows. These results also indicate that social attraction may be a strong motivator for dairy cows and social attraction between animals needs to be considered when using VH technology to manage sub-groups within a herd.

Figure 10*: Two virtual fences separate groups of grazing dairy cows*

Subprogram 4: Identify opportunities for labour savings through the application of VH in sheep wool and meat enterprises.

This subprogram was led by Dr Danila Marini and the University of New England and CSIRO teams at Armidale, NSW who had to use manual neckbands and small numbers of animals, as an automated system has only been developed for cattle.   This manual neckband technology requires people to deliver the cues manually and thus only 1-2 animals can be controlled by one person at any one time. Despite these limitations, considerable basic R&D work was done with sheep to identify the cues required and the application of the VH technology to improve pasture utilisation, herd sheep and exclude sheep from certain environmentally sensitive areas. The key results from this subprogram included:

> **Determine the appropriate level and duration of electrical pulse and audio cues to sheep to enable sufficient control, without adversely affecting animal welfare.**

To ensure that animal welfare is not compromised through the use of a virtual fencing system, animals must have the ability to avoid the fence. Through associative learning, the sheep in the initial studies were able to respond to a benign audio cue in order to avoid the aversive electrical stimulus. A virtual fence enforced by the electrical stimulus was successful at preventing sheep from entering an exclusion zone in both an individual setting and in a group grazing situation.

The results of these initial studies identified the appropriate level and duration of the electrical stimulus that should be used in association with a benign audio cue that could be used to successfully train sheep to the virtual fence using the Garmin dog collars.

Determine the individual variation and group dynamics in sheep subjected to VH technology.

An experiment was designed that looked at the individual variation and group dynamics of a small flock of sheep in a normal paddock, as well as in response to a virtual fence. A computational model of sheep collective behaviour was constructed from this work that could be used to determine large flock movements after the application of VH technology.

The results of the computational modelling show that it took an average of 3-7 interactions with the virtual fence for learning to occur in sheep. The results also showed that naïve sheep exposed to the virtual fence as a group, have a low probability of receiving an electrical stimulus. This was seen for their first interaction with the fence (24%) and for interactions with the fence after learning (10%). These results are in sharp contrast to results of naïve sheep trained individually where a much greater proportion of sheep received the electrical stimulus. As with previous studies, interactions with the fence was affected by surrounding sheep, with sheep in the front of the flock receiving an audio or electrical stimulus turning other sheep around and away from the fence.

Another study looked at what proportion of sheep in a flock would be required to be controlled with a virtual fence without affecting efficacy during short term deployment. Sheep were allocated to small groups (n=9) with either, 0%, 33%, 66% or 100% of the sheep in each group wearing VH neckbands. Exclusion from a section of the paddock was successful for sheep in the 100% and 66% groups but not the 33% or 0% groups. Thus it appears that at least 66% of the sheep in a small flock require neckbands capable of delivering the appropriate cues for virtual fencing.

Determine the effectiveness of VH technology to restrict movement of sheep to improve pasture utilisation.

An intensive grazing study investigated whether virtual fencing could be used for applications such as strip grazing or techno grazing for sheep. Small groups of sheep were allocated to being constrained either by an electric fence or a virtual fence in a strip grazing situation where sheep had access to a new pasture allocation each day.

In this study, sheep in both the virtual fence and the electric fence treatments were successfully restricted to their plots throughout the trial. Consumption of pasture was similar as there was no difference between treatments in the crop biomass removed after each grazing. Furthermore, implementation of the virtual fence in a small area did not impact the behavioural patterns of the sheep. The results of this study show that using virtual fencing to manage intensive grazing of a small group of sheep in a restricted area is effective and does not negatively impact their welfare.

Determine the effectiveness of VH technology to encourage movement of sheep in practices such as mustering.

A herding trial used 12 Merino ewes that had not been previously exposed to a VH technology. The sheep were first trained in pairs to a front virtual fence to make sure they had learnt the system before it was used to herd them. For herding, two groups of 6 sheep each were herded across a paddock (approximately 140 m x 80 m) using the single back fence method that implements a single virtual fence which sequentially follows behind the animals as they move down the paddock. Once the flock of sheep reached the end of the paddock, they were held there with the virtual fence for 30 minutes before the fence was removed and they were walked back up to the other end of the paddock using the back-fence method again. Herding was highly dependent on the flock's motivation to move, with herding across the paddock ranging from 10 minutes to 1 hour. Herding was slow if sheep were camping or grazing, however if one sheep in the flock of six initiated movement then the remaining sheep tended to follow and reached the end of the paddock quickly. Once at the end of the paddock, sheep were successfully contained for 30 minutes. When the fence was removed to allow them to re-traverse the paddock, they quickly were able to walk through the location of the previously existing fence.

Welfare responses to VH technology

Much of this work to examine the effect of VH technology delivered by manual cues on subsequent animal welfare status was conducted as part of PhD studies conducted by Ms Tellisa Kearton. In order to optimise the likelihood of successful implementation, it is important to understand whether the use of the audio cue and electric stimuli that are an integral part of virtual fencing, have any welfare impacts on the animals.

A study was conducted to compare the impact of the audio cue and the electrical stimulus with known stressors in sheep, these being dog barking and restraint. During the trial, 80 Merino ewes were assigned to either of five treatments; control, audio beep, dog bark, restraint or electrical stimulus treatments.

The restraint treatment showed an elevated cortisol response when compared with the control. No differences were seen between the other treatments and the control sheep. There were no differences in body temperature in response to the treatments. When comparing the behaviours of the animals, sheep that were in the bark and beep treatments showed more vigilance (head up and looking around) compared to the control sheep. Sheep that received the electrical stimulus showed more aversive behaviours compared to the control sheep. Ranking of the least to most aversive treatments taking into account behavioural and physiological measurements were: Control<Beep<Barking Dog<Electrical stimulus<Restraint. The results show that any impacts on animal welfare of the audio and electrical cues used in VH technology were considerably less than simple constraint of the sheep.

For her second study, Tellisa investigated the stress responses of sheep that were trained to the virtual fence using correct training techniques, compared to poor training techniques. When sheep are correctly trained to the virtual fence they learn to react to the audio warning and avoid receiving the subsequent electrical stimulus. This provides predictability (the audio warning) and controllability (avoiding the electrical stimulus by stopping or turning around) of their interaction with the virtual fence. Having good predictability and controllability is an important aspect of virtual fencing that ensures acceptable welfare status of the animals is maintained.

Subprogram 5: Identify considerations and challenges for integration and adoption of VH technology.

Virtual herding technology is only in its initial stages of commercialisation as a form of virtual livestock management. The decision to adopt and apply this new technology by the livestock industries is likely to require livestock farmers to navigate a range of uncertainties, risks and complexities and involve learning, practical, managerial, and ethical considerations. It was therefore critical to propose some possible pathways for adopting VH technology to enable effective routes to smart livestock farming. This subprogram was led by Ms Nikki Reichelt and The University of Melbourne team at Parkville, Victoria and the key results from the subprogram included:

Participatory Technology Assessment Process for VH technology

The approach to understanding the adoption and integration issues with virtual herding technology is based on a Participatory Technology Assessment (PTA) process. The PTA process was undertaken to understand the challenges and opportunities for adopting virtual herding technology. It involved workshops and discussions that were conducted with a range of stakeholders (n=100) across the livestock value chain who may have had an interest in or be impacted by virtual herding technology for the purpose of deliberating on the opportunities, risks, and challenges with this technology.

Based on the data collected through the focus groups and engagement workshops with producers, agricultural advisers, natural resource managers, food processors, food retail companies and state government departments, it was apparent that there were 6 key considerations that are likely to have a significant influence on the adoption process for virtual herding technology. The 6 key considerations are grouped as primary considerations for producers at the farm scale (immediate influence) and secondary considerations based on the broader socio-technical system (incidental influence).

Primary considerations on-farm

1. *Anticipated individualised benefits:*

The responses by livestock producers and agricultural consultants suggest that the decision to adopt virtual herding technology is likely to be influenced by identifying the potential benefits for the whole farm system or "triple bottom line" from implementing a virtual herding system. A single benefit may not offer enough incentive.

2. *Demonstrated Proof of Concept and product performance:*

Group discussions with livestock producers highlighted the importance of having a fully developed Proof of Concept and demonstrated product performance that is substantiated with scientific and experiential evidence. Based on the responses from the focus groups, livestock producers would value access to published research data and visits to local demonstration farms to build their individual case for adoption. In addition, a Cost Benefit Analysis (see next section) is likely to provide an important indication of the economic advantages that can be gained from adopting virtual herding technology.

3. *Accessible 'fit-for-purpose' support system:*

There is a need to support livestock producers in adopting and using virtual herding technology because it will involve the improvement of ICT skills, learning new technical and management practices, greater understanding of animal behaviour and interpreting new data outputs for better decision making. A lack of available support at the adoption, installation and implementation stages may hinder the decision to adopt virtual herding technology in the first place or may result in the rejection and abandonment of the technology after adoption.

<u>Secondary considerations beyond-the-farm-gate</u>

4. *Principled governance of VH data:*

A common concern for and interest of the livestock producers and other stakeholders was how the data generated through the VH system would be governed, protected, used, and owned. These questions remained mostly unresolved during the focus groups and engagement meetings, althoughowever the commercial developer, Agersens, did provide some assurances to livestock producers with regards to data ownership and privacy

5. *Proactive public communications to support the social license for virtual herding:*

It became apparent across the focus groups and engagement meetings that managing public perceptions of VH technology to maintain the livestock producers' social license to operate were an important consideration. All the stakeholder groups accentuated the importance of clearly communicating the implications for animal welfare from the use of virtual herding technology based on scientific research or detailing how the technology works to avoid any misconceptions

6. *Regulating VH use:*

The topic of regulating the use of VH technology, was a key theme that was discussed predominantly by the natural resource managers, food retail companies and the dairy processor. Their interest in regulating the use of VH was driven by their organisation's need for compliance with meeting market specifications for premium brands, reaching natural resource management targets or minimising the risk of causing animal welfare issues. The regulation of VH technology use may therefore become a requirement for compliance purposes or as a voluntary measure in the form of Best Management Practices.

Virtual Herding technology adoption strategy

Adoption pathways were developed in association with a Consultative Panel that comprised a wide range of people representing progressive farmers, RDCs, Agricultural consultants, technical people from key R&D providers together with a representative of Agersens. These people were sent a comprehensive briefing paper and then engaged in a 2 hour Zoom meeting towards the end of the Project to discuss the adoption of VH technology. The key messages from the discussion with the Consultative Panel were:

- VHT is a complex technology and therefore requires significant adoption support
- The Generic Transfer of Technology model is not enough but a multi-approach was required.

- Adoption pathway needs to be adaptive with a level of customisation built in
- Value proposition for the technology needs to be better defining and refining
- Adoption pathway may need to be multi-staged.

The culmination of this extensive engagement with all sectors of the livestock industries through the supply chain from producers to retailers was the development of an adoption strategy for VH technology. The complete strategy document is provided in this Final Report as Appendix 7.5. The purpose of the Virtual Herding Technology Adoption Strategy was to provide the context for adoption, suggested pathways for beef, dairy and sheep/mixed production industries and present a set of final recommendations that set out the roles and responsibilities for the governance of VHT adoption. The adoption pathways for the respective livestock industries aim to build capabilities in VH technology applications while increasing support for adoption over time to ensure end-users make informed decisions about this exciting innovation.

Benefit Cost Analysis (BCA) of use of VH technology for the livestock industries.

Virtual Herding technology offers potential to move livestock with less labour and improve grazing management. Feed and labour are significant costs on beef, sheep and dairy farms and VH technology offers potential for improved efficiency in both of these areas. The project team at The University of Melbourne investigated the break-even cost that farm businesses could invest in VH technology based on anticipated benefits. They conducted benefit cost analyses for 3 livestock production systems; pasture based dairy, extensive beef grazing and a mixed farm system comprising livestock and cropping. The price of VHT has yet to be established, so the approach taken in this study was to calculate the break-even cost per animal that the farm business could pay for the technology based on the anticipated benefits. The 'break-even' capital cost of VH technology was estimated for a range of applications on each case study farm. A partial discounted net cash flow budget over 10 years was used assuming a 15% internal rate of return (nominal) was required to justify investing in VH technology. The capital cost included cow neckbands and associated infrastructure but not on-going registration fees. A 5-year lifespan of the VH neckbands was assumed.

<u>Pasture-based dairy</u>

The dairy farm was in West Gippsland with long-term rainfall of approximately 1,000mm. The milking area has approximately 192 ha available for grazing with a milking herd of 680 cows. Cows calved between late July and late September. Annual milk production was approximately 430 kg milk solids/cow. In addition to grazed pasture, cows were fed 1.2 - 1.8 t DM/yr of a concentrate supplement as well as conserved fodder as required.

The results of the BCA indicate that if the VH technology is used to splitting daily pasture allocation to enable later milked cows to have access to a greater quantity and higher quality of pasture then the maximum the farmer could pay is $238 per cow as a result of potential milk yield increases for these later milked cows. The break-even cost was only $77/cow for either reduced pugging damage with more flexible grazing, or fetching cows for milking to save labour and vehicle use.

<u>Sheep-beef farm</u>

The sheep/beef farm was in Western Victoria with long-term annual rainfall of 550mm. The home farm comprised approximately 2,800 ha with 320 ha of this being leased. There was also a block of approximately 480 ha located about 40 km north of the home farm and another of approximately 440 ha located about 100 km south. These two blocks are primarily grazed by cattle. There are approximately 7,500 mature merino ewes, 500 rams, and 2,500 replacement ewes. In addition, there are approximately 2,300 mature beef cattle and approximately 1,700 calves.

Approximately 60% of the home farm is undulating to steep with lots of gullies. The cattle complement the sheep by grazing more of the slopes and gullies on the home farm whereas the sheep tend to overgraze the pasture on the hills, which impacts on pasture production and persistence.

The results of the BCA indicate that the investment in VH technology on out-blocks to manage beef cattle appeared to be worthwhile, but it does not appear to be for sheep even when multiple benefits are combined. While the break-even cost of using VH technology to save labour and control grazing was about $400/cow, any use of VH technology with sheep to either, improve pasture utilisation, increase lamb survival or manage riparian zones was less than $100/ewe.

<u>Extensive beef system from northern Australia</u>

The beef case study farm is a breeder operation in central, western Queensland. The climate has a summer dominant rainfall pattern that is highly variable (mean annual rainfall of about 430 mm with range 107 – 1026 mm) and the region has a short and highly variable growing season of approximately 2-3 months. The property was 7,000 ha and typically carries a herd of 400 breeders (F1 Wagyu/Angus) and calves until weaning. The property is divided into 8 paddocks which allow some control of grazing management.

The results of the BCA indicate that if VH technology was used to assist in mustering the herd for branding and weaning, then the maximum the farmer could pay was $35/cow. However, the break-even cost of improving the carrying capacity by 20% through better pasture utilisation was $255 for each cow.

The major findings from these Benefit Cost Analyses were:

- Labour savings alone were not enough to achieve break-even costs in a realistic range.
- Pasture or livestock production gains were essential to achieving realistic break-even costs.
- High sensitivity to assumptions of production and VH technology lifespan.
- VH technology in sheep production systems does not appear to be profitable because of the large number of neckbands required.
- There are opportunities for improved environmental outcomes, in addition to the production benefits.
- Most importantly, costs and benefits will vary for individual farm businesses.

Overall program – animal welfare outputs.

Across all subprograms, one of the principal aims of the Virtual Herding project was to gather information to quantify any effects of the virtual herding technology on physiological and behavioural indices of animal welfare to ensure that the welfare of livestock is not compromised by the technology. The Project has identified some key measures of welfare assessment during the initial contact with the virtual fence, during the learning phase and during long term application of the technology.

Some of the more promising practical measures include:

- *The ratio of audio: total audio and electrical cues after the initial learning phase.*
    - This is a measure of learning to respond to the audio cue and avoid the electrical cue at the virtual fence line. This ratio often approached 90% in many of the trials in the Project. A minimum level of 80% once animals are trained, may be considered as a target for acceptable animal welfare.
- *Spatial distribution of animals within the inclusion area.*
    - Using GPS, "Heat maps" can be generated of the spread of animals in a paddock and these may indicate if there are any welfare issues. For example, animals following fixed fences may indicate a lack of understanding of where the virtual fence is located. Uniformity of the paddock and position of preferred resources such as water points should be considered when interpreting these spatial patterns.
- *Time budgets.*
    - The proportion of time the animal spends lying, walking, grazing, etc compared to accepted norms. For example, cows are motivated to achieve between 12 to 13 hours of lying time per day and disturbances in normal time budgets can indicate welfare issues. The time budget data was collected in R&D studies in the Project by the use of commercially available Ice-Qubes® and MooMonitors®, but there is potential to integrate and validate this type of data into the neckband.
- *Behavioural response to the cues.*
    - For example, how long does it take for the animal to return to normal patterns of behaviour such as grazing, after receiving the cues.

In addition to the practical measures outlined above, some of which may be used to assess the welfare of animals in commercial production, the Project has also collected data on both;

- behavioural measures, such as an ethogram or a quantitative description of the animal's behavioural response to the audio and electrical cues,
- physiological measures, such as cortisol concentration which may be an indicator of stress.

3.1 Project level achievements

Following is a description of project achievements against the activities, KPIs and outputs as specified in sections B and C of the grant agreement.

Activity and KPI no.	**KPI Description**	**Project Achievements against each KPI**
Activity B1	**Project Initiation.**	
KPI 1.1	Confirm the engagement of a project manager(Output 1a)	***Output 1(a) – Engage a project manager for the duration of the Activity.*** Dr Ray King, RHK Consultancy was contracted on 3 August, 2016 to act on behalf of Dairy Australia as the Project manager from 1 July, 2016 to 30 June, 2017. This was later extended to the end of the Project by the Steering Committee.
KPI 1.2	Provide agreed membership, governance arrangements and terms of reference for project steering committee (Output 1b)	***Output 1(b) – Establish a project steering committee responsible for oversight of the Activity. The committee will include industry and RDC representatives as well as an animal welfare agency representative. The project steering committee will agree its terms of reference which will set out its membership, governance arrangements and responsibilities.*** The Steering Committee was established in October, 2016 and contained senior representatives of each of the Project Partners, as well as a representative of an animal welfare agency (Prof. Paul Hemsworth, Director, Animal Welfare Science Centre) and two people from the livestock industry with particular interest in the VH technology. The first meeting of the Steering Committee was held in February, 2017.
KPI 1.3	Provide a list of all partner organisations and status of partner agreements, including the date signed or the date expected to be signed (Output 1c)	***Output 1(c) – Execute agreements with partner organisations.*** The Commonwealth Agreement between DAWR and Dairy Australia was signed on 22 June, 2016. The Project Management Agreement between Dairy Australia and the respective R&D providers , the R&D Corporations and Agersens (the commercial Partner) was developed, and extensively reviewed by some of the ten Project Partners, but was finally signed by all Partners before April, 2017.
KPI 1.4	Provide a list of cash and in-kind contributions for each partner, for each financial year of the Activity and the total amount of funding and in-kind contributions (Output 1d)	***Output 1(d) – Agreement on the yearly breakdown of the cash and in-kind contributions to be provided by partner organisations for the duration of the Activity.*** The cash and in-kind contributions of each partner in the Project for each year did not change and are similar to the information in the original submission and Commonwealth Agreement for the duration of the Agreement. A list of cash and

<table>
<tr><td></td><td></td><td>in-kind contributions for each Partner, for each financial year of the Project was submitted in Milestone 1 Report.</td></tr>
<tr><td>KPI 6.1</td><td>Provide a mid-way evaluation report on the Project (Output 2d)</td><td>Output 2(d) – Provide a progress report on the evaluation of the project, delivered at mid-point of the Project.

A progress report on the Monitoring and Evaluation Plan of the project was submitted in December, 2018. Some of the main outcomes for the first 2 years of the Project have been:
The Workshops in Subprogram 5 markedly increased the awareness of VH technology amongst the attendees and most of these people are very supportive of the technology, but they needed more "convincing' evidence to prove the ROI.
There has been some liaison with RSPCA as senior RSPCA staff regularly log into the Project webinars.
Several R&D collaborations have been established with other R&D providers and projects to more fully evaluate the virtual herding technology. These collaborators include AgResearch in New Zealand and the South Australian Government.
Both the SA and Victorian Governments have recently granted exemption for the use of the VH technology under experimental conditions. Already the technology can be used for commercial purposes in Queensland and Tasmania.
The Project webpages on the Dairy Australia website that were established in February, 2017 have experienced a sustained increase in "hits" during 2018.
A mailing list of about 150 people, that have expressed a genuine interest in the application of virtual herding technology, has been established.</td></tr>
<tr><td>Activity B2</td><td>Project Planning and Management</td><td></td></tr>
<tr><td>KPI 1.5</td><td>Provide a draft project plan (Output 2a)</td><td>Output 2(a) – Prepare a project plan, setting out the schedule for activities, and the human resources and financial resources required. Prepare a risk management plan as part of the project management plan.

A draft of the Project Plan was developed in the first 6 months of the Project with input from the Project team.</td></tr>
<tr><td>KPI 2.1</td><td>Provide the project plan endorsed by the steering committee (Output 2a)</td><td>Output 2(a) – Prepare a project plan, setting out the schedule for activities, and the human resources and financial resources required. Prepare a risk management plan as part of the project management plan.

This draft Plan, which identified the main activities for the first 18-24 months of the Project, was endorsed by Steering Group at their first meeting in February, 2017. This Project plan was accepted by the Project partners, in particular, Agersens who were to supply the pre-commercial prototypes of eShepherd. The plan was presented in the Milestone 2 Report.</td></tr>
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KPI 2.2	Provide the communication and extension plan (Output 2b)	***Output 2(b) – Prepare a communication and extension plan, setting out the schedule for communication and extension activities, and the human resources and financial resources required. The plan should include material that addresses animal welfare issues.*** The Communication and Extension Plan was developed in conjunction with the Communications group at Dairy Australia, who advised on communication channels such as webpages and social media. Templates for media releases, fact sheets, briefing notes and powerpoint presentations were approved by the Commonwealth Government. This Communication and Extension Plan was presented and endorsed at the first Steering Group meeting in February, 2017. This Communications and Extension Plan was presented in the Milestone 2 Report. The templates for the powerpoint presentations and Newsletters were changed regularly as the logos for the respective Project Partners were updated.
KPI 2.3	Provide the monitoring and evaluation plan (Output 2c)	***Output 2(c) – Prepare a monitoring and evaluation plan, setting out timeframes for activities to be delivered, and the human resources and financial resources required.*** The Monitoring and Evaluation Plan was developed with support from Ruth Nettle at The University of Melbourne, who leads the Project subprogram that identifies the challenges for integration on-farm, assesses costs and benefits and the value of on-farm VF technology to different stakeholders. This Monitoring and Evaluation Plan was presented in Milestone 2 Report.
KPI 10.1	Provide the final evaluation of the Activity	The completed Monitoring and Evaluation Plan is provided in this Final report as Appendix 7.3
Activity B3	**Communication and extension activities**	
KPIs 2.4, 3.4, 4.1, 5.4, 6.2, 7.4, 8.1 and 9.2	Provide an update and account of completed communication and extension activities every Milestone Report (Output 3(a), 3(b), 3(c) and including publications as Output 6(f) from Activity 6B.	***Output 3(a) – Identify target audiences and establish appropriate contacts with innovative primary producers that may be directly involved in the Project; appropriate producer organisations and networks (such as Best Wool Best lamb grower groups, and the NSW Innovative Dairy Group); Rick Llewellyn and the project team of the CSIRO sheep project, relevant sections of State Government Departments that control animal welfare legislation; individual livestock producers through the relevant RDC contacts; Ian Reilly, Agersens (who is commercialising the VF technology); and animal welfare agencies, in particular, the RSPCA.*** A Farmer Panel which was made up of about 25 progressive farmers from the major livestock industries was established in the first year of the Project. Members of the Farmer Panel were

		regularly updated with the Progress of the Project and were often called upon to contribute to the Project, particularly as members of the focus groups established in Subprogram 5. The Project Manager established a close relationship with Agersens and regularly met with their Technical staff to discuss the progress of the project and issues about use of the pre-commercial prototypes of eShepherd in the experimental program. The technical information on the assessment of the welfare of animals exposed to VH technology was collected from a number of experiments and made available to State Government agencies that control animal welfare regulations. As a result, VH technology can be used commercially in Queensland and Tasmania and may be used in R&D experiments that have been approved by the relevant Animal Ethics Committees in the other States. During the Project, discussion with these other States has been positive and it is hoped that VH technology may be used commercially in these other States in the near future. Members of the Project team have continued to present results of this project and discuss the implications of virtual herding technology with livestock producers, animal welfare agencies (RSPCA), students and advisors at industry seminars and workshops. ***Output 3(b) – Implement communication and extension plan, and promote project activities and outcomes at annual project team workshops, regional and national scientific livestock conferences (Australian Society of Animal Production, Australian Dairy Science Symposium) and regional industry conferences and seminars convened by industry groups and RDCs for the major livestock industries.*** The communication activities throughout the Project were guided by the communication and extension plan. Members of the Project team presented results of this Project and discussed the implications of virtual herding technology at a wide variety of livestock industry conferences/seminars. A full list of the communications with industry groups is presented in the Publication List in Appendix 7.1. A video that explains how the virtual herding technology works with examples from the Project of how animals respond to the technology is available on the Dairy Australia website and has had over 600 views (https://www.dairyaustralia.com.au/feed-and-nutrition/current-research/smart-farms/virtual-herding#.X6R4ZizivIU). Nine Project Newsletters have also been produced by the Project and they are on the Dairy Australia website at: https://www.dairyaustralia.com.au/farm/animal-management/technologies/virtual-herding-program. ***Output 3(c) – Publish research findings in appropriate scientific journals, conferences and industry seminars, and through websites of the livestock RDCs and partner***

		organisations that may be accessible by primary producers and the general community. A full list of the communications with industry conferences and seminars is presented in the Publication List in Appendix 7.1. In addition, a series of 11 Technical Notes that provides technical information about how VH technology and how it may be used by the Australian livestock industries, including the results of some of the R&D conducted in the Project as case studies have been produced and are also presented in Appendix 7.6. This series of Technotes provide a legacy of some of the main achievements of the Project. ***Output 6(f) – Develop manuscripts for submission to high impact scientific journals.*** An update of both the scientific and industry papers and presentations was provided in each Milestone Report This Project has generated a significant number of scientific publications. Since the Project began, 18 research papers have been accepted and published in Scientific Journals while another 2 have been submitted. A complete list of Communication and extension activities is provided in Appendix 7.1.
KPI 10.2	Provide a list of prepared, submitted and published research (Outputs 3(c) and 6(f))	***Output 3(c) – Publish research findings in appropriate scientific journals, conferences and industry seminars, and through websites of the livestock RDCs and partner organisations that may be accessible by primary producers and the general community.*** ***Output 6(f) – Develop manuscripts for submission to high impact scientific journals.*** The full list of the prepared, submitted and published scientific research papers is presented in the Publication List in Appendix 7.1.
Activity B4	**Optimising the Animal response to VF technology**	
KPI 3.1	Provide and update on research undertaken to optimise cues and controls to restrict animals and to determine cattle responses to moving and complex virtual fences (Outputs 4a, 4b and 4c)	***Output 4(a) Identify and establish suitable experimental sites and required resources, including obtaining appropriate AEEC approval*** Four experiments were conducted at CSIRO Armidale, using the facilities and cattle herd at Chiswick and pre-commercial prototype automated neckbandss provided by Agersens. Animal ethics approval was granted from the AEEC (AEC16/28) for these animal studies. ***Output 4(b) Conduct controlled experiments to determine how cattle respond to moving and complex virtual fences, including behavioural and welfare assessments.*** A virtual fence was shifted several times at 3-4 day intervals to provide cattle more access to a paddock. Within 24 hours of

		moving the virtual fence, cattle were able to access the new grazing area and over 90% of the time, animals were contained within the new area. Furthermore, most of the cues that the cattle responded to were audio cues with the electrical stimulus being imposed in less than 20% of the cases. There were no differences in the behavioural responses to changes in the virtual fence and there were no lesions or rubbing observed around the neckband in any of the cattle ***Output 4 (c) Conduct research to optimize cues and controls necessary for the most efficient operation of VF technology to restrict animals that is consistent with acceptable welfare outcomes for cattle.*** Results indicated that lower pulse levels were not aversive enough to stop cattle whereas durations of 1 second or more were too long and elicited prolonged and undesirable behavioural responses. Individual cattle showed high variation in both the behavioural response to the stimuli and their learning rate, although the variation tended to reduce when animals were held in groups.
KPI 5.1	Provide an update on research undertaken to encourage the movement of cattle by VF technology (Output 4(d)).	***Output 4(d) – Conduct controlled experiments to determine how to encourage cattle to move from one location to another using VF technology.*** The results of the April, 2017 experiment that investigated the response of cattle to moving fences, indicated that cattle responded well to changes in virtual fences and remained within new inclusion areas when the virtual fences were moved every 3-7 days. The next phase of the program was to determine whether changing the virtual fence much more regularly could herd the animals or quickly move them from one location to another when required. The results of a pilot study suggested that cattle could be herded to a desired location by using the "back-fence" approach. In a subsequent experiment, three different herding fence designs were trialed, but the use of the simple "back fence" design that followed behind the group of cattle is likely to be most successful herding strategy. The implementation of a simple moving back fence could move the group of cattle down a 300 metre long paddock in less than 15 minutes.
KPI 7.1	Provide an update on research undertaken to determine the capacity of VF technology to control individual cattle in the herd (Output 4(e)).	***Output 4(e) - Document the longer-term behavioural and welfare impacts of VH technology*** Most of the early experiments in this Project examining the use of VH technology have been short term (up to about 2 weeks). An experiment was conducted to assess animal welfare measures when virtual fencing technology was imposed for longer term (4 weeks). In this experiment, an electric fence was compared to a virtual fence to containing cattle for at least 4 weeks. The virtual fence was successful in keeping the cattle within their prescribed areas for the vast majority of the time. The animals learnt the association between the audio and electrical pulse cues. The ratio of electric cues to total cues was usually less than 0.2 which indicates acceptable animal welfare. Cattle in the virtual fence treatment had a longer total standing time and tended to have a shorter lying time, although these differences were small and biologically insignificant, falling well

		within typical cattle behavioural patterns. There was no significant effect of fence type on faecal cortisol concentrations. In conclusion, the results of this study provided evidence that cattle welfare was not compromised by the virtual fencing system over a longer term period.
KP 9.3	Provide a final account that summarises the findings and analysis completed on strategies to optimise the animal response to virtual herding technology, incorporating the results of final and controlled and field experiments (Outputs 4f and 4g)	***Output 4(f) - Conduct field experiments to demonstrate the application and effectiveness of specific applications of virtual herding technology to restrict or encourage movement of cattle.*** In one of the earlier experiments at Armidale we demonstrated that the implementation of a simple moving back fence could move the group of cattle down paddock by watching the cattle and manually moving the virtual fenceline as they moved forward from the back fence. Since then Agersens have incorporated a continuous "mob move" facility in their automated system which identifies when all animals are in front of the back VF and then automatically moves the fence forward to move the herd down the paddock. They have demonstrated this with a mob of 250 beef cattle at Hillalong Station in central Queensland. ***Output 4(g) Document the welfare assessment of the application of virtual herding technology in cattle from controlled and field experiments.*** Across all subprograms, one of the principal aims of the Virtual Herding project was to gather information to quantify any effects of the virtual herding technology on physiological and behavioural indices of animal welfare to ensure that the welfare of livestock is not compromised by the technology. The Project has identified some key measures of welfare assessment during the initial contact with the virtual fence, during the learning phase and during long term application of the technology and after the initial learning phase. Some of the more promising practical measures include: *The ratio of audio: total audio and electrical cues after the initial learning phase.* • This is a measure of learning to respond to the audio cue and avoid the electrical cue at the virtual fence line. A minimum level of 80% once animals are trained, may be considered as a target for acceptable animal welfare. *Spatial distribution of animals within the inclusion area.* • Using GPS, "Heat maps" can be generated of the spread of animals in a paddock and these may indicate if the animals use the whole inclusion area and whether there are any welfare issues. *Time budgets.* • The proportion of time the animal spends lying, walking, grazing, etc compared to accepted norms. *Behavioural response to the cues.* • For example, how long does it take for the animal to return to normal patterns of behaviour such as grazing, after receiving the cues.

KPI 10.3	Provide a final account that summarises the findings and analysis completed on strategies to optimise the animal response to VH technology, incorporating the results of final controlled and field experiments from Outputs 4(f) and 4(g)	***Output 4(f) - Conduct field experiments to demonstrate the application and effectiveness of specific applications of virtual herding technology to restrict or encourage movement of cattle.*** ***Output 4(g) Document the welfare assessment of the application of virtual herding technology in cattle from controlled and field experiments.*** The final account of these studies to optimise the animal response to VH technology is provided in Section 3 of this Final Report, under Subprogram 1.
Activity B5	**Determine best livestock and pasture management for intensive Dairy and Beef through more controlled pasture allocation**	
KPI 3.2	Provide an update on year one preliminary findings (Outputs 5a and 5b)	***Output 5(a) Identify and establish suitable experimental sites and required resources, including obtaining appropriate AEEC approval.*** One experiment has been conducted at Tasmanian Dairy Research Farm (TDRF), Burnie using 60 mid-lactation dairy cows from the 360 head dairy herd, and manually dropped fences to simulate the virtual herding technology to improve pasture utilisation. AEEC approval was obtained for this study in December, 2016 (A0016234). A second AEEC approval (A0016519) was obtained in May, 2017 for the grazing study with drop fences and 80 replacement heifers to investigate more frequent changes to pasture allocations. ***Output 5(b) Conduct field experiments to quantify how VH may be applied to increase pasture utilization through more regular and more tightly controlled stock movements.*** A suitable version of the pre-commercial prototype of eShepherd was not available until the second year of the Project. Thus a couple of simulation studies were conducted, where electric fences were physically changed on a regular basis. A simulation experiment with lactating dairy cows examined the effect of an extreme grazing regime of providing the daily pasture allowance in 7 smaller grazing allocations compared to the standard 2 allocations each day. The extreme grazing regime failed to improve performance, possibly because of the lower pasture allocation, uneven grazing pressure and their effects on rumination.
KPI 5.2	Provide an update on year two preliminary findings (Outputs 5c and 5d)	***Output 5(c) – Establish forage crops for field trials*** ***Output 5(d) – Conduct field experiments to quantify how VF can be applied to face management of forage crops.*** The two outputs above were technically not feasible and could not be achieved because of technical issues with the GPS

		functionality of the eShepherd™ neckband, which only allows accuracy of the virtual fence to +/- 5 meters, at this stage. The sensitivity of the GPS in the eShepherd™ neckband needs to be within +/- 1 metre to enable intensive face management of fodder crops. As work on forage crops was not possible within the time frame of the Project, other experiments were conducted which considerably strengthened the other Project Outputs relating to the use of VH technology to improve pasture utilisation in intensive dairy and beef production systems, and the factors controlling the response to VH technology. These were more basic studies used manually applied cues rather than delivering them through the automated eShepherd™ system. The results of one such experiment indicated that pre-exposure to electrical stimulus via electric fencing results in more rapid associative pairing of the audio and electrical stimuli. As dairy cattle regularly interact with electric fencing when reared on dairy farms they may be more "primed" to rapidly accept VH technology. Another experiment established that dairy heifers learnt the association between the cues much better when exposed to the technology at older ages, up to 22 months of age, and indicate that replacement heifers should be trained with VH technology just before they enter the milking herd at about 24 months of age.
KPI 7.2	Provide an update on year three preliminary findings (Outputs 5e and 5f)	***Output 5(e) "Conduct field experiments to quantify how VF can be applied to rotational grazing on heifer rearing blocks"*** Replacement heifers were allocated to two treatments that differed in frequency of pasture allocation (either the standard at twice per week or where heifers gain access to new pasture, daily). Physical fences were used to simulate virtual fencing. The results indicated that the daily allocation of pasture to pregnant heifers increased liveweight gain, the duration of rumination and pasture regrowth although there were no effects on pasture consumption. ***Output 5(f) "Conduct field experiments to quantify how virtual fencing can be applied to modifying paddock layout through non-linear and moving virtual fencelines, for dairy and beef industries".*** An experiment was conducted in 2018 that was designed to investigate the ability of constraining dairy cows into the daily pasture allocation by the use of VH technology compared to traditional electric fence technology. In the study, 30 lactating dairy cows were shifted daily to new paddocks that provided 16 kg DM/day of available pasture. Video data and visual observations indicated that the virtual front-fence successfully contained the experimental herd within the inclusion area of pasture allocation. Group responses to stimuli were also evident, with cohorts of cows moving away from the virtual front-fence when an adjacent individual cow received the audio signals. In this comparison, the results suggest that the VH technology did not adversely affect milk production, body

		weight changes or the spatial distribution of pasture consumption**.**
KPI 9.4	Provide a final account that summarises the findings and analysis completed on more controlled pasture allocation strategies to improve pasture utilisation, and incorporating the results of final field studies (Output 5g) and development of agreed protocols (Output 5h)	***Output5(g) Determine and conduct any final field experiments based upon gaps identified in the results of previous studies in Outputs 5b, 5d, 5e and 5f.*** An experiment was conducted to examine modifying paddock layout for intensively grazed beef cattle. Groups of 10 Angus heifers were cell grazed with either electric or virtual back and front fences. All heifers were offered about 10 kg DM/day pasture and there was no differences in the amount they consumed (7.1 kg DM/day) or weight gain over 2 weeks, being 6.5 kg and 12.4 kg for electric and virtual fence treatments, respectively. An interesting observation in this study was that one group of heifers in the virtual fence treatment often grazed outside of their cell, particularly when they had visual contact with another group. This observation 36mphasizes the social attraction between individuals in a herd and this effect on the response to virtual fences. ***Output 5(h) Establish and document agreed protocols for use of virtual herding to increase pasture utilisation through more controlled pasture and forage allocation.*** The work at UTAS in Tasmania demonstrated that dairy cows would only require a minimum of about 3 days of training to the VH technology before they can be controlled by the technology in simple and common strip grazing systems. This Project used VH technology to try to improve pasture utilisation in several situations. When VH technology was simulated by physically moving fences, replacement heifers improved weight gain. VH technology was used to study pasture utilisation when applied in strip grazing or techno grazing systems for dairy and beef cows, respectively. Simple protocols have been prepared to train cattle to respond appropriately to VH technology in less than 4-5 days so that the technology may be applied to increase pasture utilisation through more controlled pasture allocation. While not demonstrated in this Project, VH technology may be able to improve pasture utilisation by ensuring fresh pasture is available at times that the animals are naturally inclined to graze, rather than when it is convenient for the dairy farmer to move fences. Other applications could be incrementally shifting the grazing front as cows return from the dairy to ensure animals at the end of the milking order can access to fresh pasture.
KPI 10.4	Provide a final account that summarises the findings and analysis completed on more controlled pasture allocation strategies to improve pasture utilisation, and incorporating the	***Output5(g) Determine and conduct any final field experiments based upon gaps identified in the results of previous studies in Outputs 5b, 5d, 5e and 5f.*** ***Output 5(h) Establish and document agreed protocols for use of virtual herding to increase pasture utilisation through more controlled pasture and forage allocation.***

	results of final field studies (Output 5(g)) and development of agreed protocols (Output 5 (h)).	The final account of these studies on more controlled pasture strategies and protocols for agreed protocols is provided in Section 3 of this Final Report, under Subprogram 2.
Activity B6	**Determine best sub-herd and individual animal management for dairy and beef**	
KPI 3.3	Provide and update on the experiments to quantify how cues can be customised and used to control individual cow movement within a herd and improve animal performance and welfare (Outputs 6a and 6b)	***Output 6(a) Identify and establish suitable experimental sites and required resources, including obtaining appropriate AEEC approval.*** Experiments were conducted at new purpose built facilities at the University of Sydney property, Mayfarm at Camden. Animal ethics approval was granted from the AEEC (Approval number 2016/1114 "Cattle behavioural and learning responses to a virtual fence") for studies to investigate the response of individual cows to cues and controls (visual, audio and electrical) of VH technology. ***Output 6(b) Conduct field experiments to quantify how VH cues can be customized and used to control individual cow movement within a herd to improve animal performance and welfare.*** Individual dry cows were tested for their ability to respond to an audio cue followed by the electrical stimuli. Animals either, tolerated, minimized or avoided the cues. A subsequent study investigated how the responses of individual cows may change when they were put into groups. The initial observations indicated that if one cow failed to respond to the cues and run through the virtual fence, all cows tended to follow, despite some of them previously avoiding the virtual fence. It seems that the "herd" mentality may override the response of individuals.
KPI 5.3	Provide an update on experiments to determine how VF can be applied to control individual or sub-herd cattle location and movement, and enhance cow movement to and from the dairy within automatic and conventional milking systems (Output 6(c)).	***Output 6© – Conduct field experiments to determine how VF can be applied to control individual or sub-herd cattle location and movement, and enhance cow movement to and from the dairy within automatic and conventional milking systems.*** To contribute to this output, two experiments were conducted to assess the role that individuality and feed motivation play in individual and group learning of, and response to, VH cues. There appears to be little difference between individual or group learning of virtual fence cues, although within a group, some individual animals may not test the virtual fence as often. Learning of the cues occurred within 3-4 tests and this learning was retained irrespective of animals being in groups or being tested individually.
KPI 7.3	Provide an update on the experiments to optimise the VF system to control cattle location and movement in specific situations to optimise	***Output 6(d) – Conduct field experiments to optimise the VF system to control cattle location and movement in specific situations to optimise individual feeding and to restrict cattle from environmentally sensitive areas for dairy and beef systems.***

	individual feeding and to restrict cattle from environmentally sensitive areas. (Output 6(d)).	An experiment under artificial conditions was conducted to investigate the role of hunger on the group response to virtual fencing (VF). The two groups of cows were fed either maintenance level or *ad libitum* and it was evident that there was an effect of hunger, with up to 25% of the cows on the maintenance feeding level crossing the virtual fence to reach the feed. None of the *ad libitum* fed cows breached the virtual fence line. A second study on the role of hunger was conducted, but under more practical conditions. A group of 12 cows were strip-grazed using a virtual fence, whereby the fence was moved daily for 10 days to offer a fresh allocation. However on 2 of those days, the virtual fence was not moved, and the cows were left to graze the residual pasture in the previous day's allocation, to mimic the effect of hunger. Cows had more interactions with the virtual fence on the "held off" days and spent more time in the exclusion zone compared to the days when cows received a daily fresh allocation. However, overall, the VH cues were sufficient to maintain the group of cows within a pasture allocation the majority of the time, even though they were hungry. It was also evident from this experiment that there is a social element to cow interactions with a virtual fence, where individuals were observed responding to the behaviour of a herd mate. To address the second part of Output 6(d), an experiment was conducted on a commercial farm in South Australia in 2019 to investigate the potential for virtual fencing technology to manage cattle around environmentally sensitive areas. A group of 20 Santa Gertrudis cattle were placed into the trial paddock and a virtual fence line was set to exclude the animals from an area containing gum saplings. The fence line remained activated for 6 weeks but did move during this time. The saplings were successfully protected from being grazed by the cattle and there was clear indication of greater pasture growth within the exclusion area where cattle were not present.
KPI 9.5	Provide a final account that summarises the key learnings from determining best sub-herd and individual animal management for Dairy and Beef to accelerate on-farm adoption of use of virtual herding technology, (Output 6e)	***Output 6(e) – Compile key learnings from the use of virtual herding to control sub-herd and individual cattle management to accelerate on-farm adoption.*** The ability of the VH technology to keep two groups of dairy cows separated <u>within</u> the same paddock was investigated at Camden. Two groups of 12 cows each were placed at opposite ends of 150 metre paddock. Each day the two groups were allocated another ~20m strip of fresh pasture allocation and progressively moved towards each other. When the distance between the two groups had been reduced to about 30 metres, two cows moved over to the other group and did not return. Based on the results of this experiment VH technology can be used to separate groups of cows in a paddock, but a minimum distance of about >50m is required. Similar to the results of most other experiments, the results also indicate that social attraction may be a strong motivator for dairy cows and social attraction between animals needs to be considered, particularly when using VF technology to manage sub-groups within a herd.

KPI 10.5	Provide a final account that summarises the key learnings from determining best sub-herd and individual animal management for Dairy and Beef to accelerate on-farm adoption of use of VH, incorporating 6(e)).	***Output 6(e) – Compile key learnings from the use of virtual herding to control sub-herd and individual cattle management to accelerate on-farm adoption.*** The final account of the key learnings on use of VH technology for sub-herd management is provided in Section 3 of this Final Report under Subprogram 3.
Activity B7	**Identify opportunities for labour savings through the application of virtual fencing in sheep wool and meat enterprises**	
KPI 4.2	Provide an update of fundamental research to determine appropriate cues and controls required to control sheep, without compromising animal welfare (Outputs 7a and 7b)	***Output 7(a) Identify and establish suitable experimental sites and required resources, including obtaining appropriate Animal Experimentation Ethics Committee (AEEC) approval.*** Resident experimental sheep from the CSIRO Chiswick property in Armidale, NSW were used in the experiments and manually controlled commercial dog training equipment, which comprised a collar (Garmin TT15, Australia) and GPS hand-held unit (Garmin Alpha 100, Australia) were also used, because there is no automated system suitable for sheep. Animal ethics approval was granted from the AEEC (AEC16/28) for the following animal studies. ***Output 7(b) Conduct detailed fundamental research to determine the appropriate level and duration of electrical stimulation and audio cues to sheep to enable sufficient control, but not compromise both behavioural and physiological aspects of animal welfare.*** Two animal experiments were conducted between February and September, 2017. The optimum level and duration of electrical stimulus was established by studying the response of sheep to different levels of electrical stimulus in association with the audio cue. The appropriate electrical stimulus in the Garmin dog collar was level 4, or equivalent to 36 mA and 20us. The results of the second study showed the importance of the audio cue given before the electrical stimulus, as animals that were given the warning of an audio cue prior to receiving the electrical stimulus were less likely to display an unfavorable behavioural response to the stimulus, such as jumping and running forward. In these studies, a virtual fence enforced by the electrical stimulus was successful at preventing grazing sheep from entering an exclusion zone in both an individual setting and in a group grazing situation.

KPI 6.3	Provide an update on the individual variation and group dynamics in sheep controlled by VF technology (Output 7(c)).	***Output 7(c) – Conduct field experiments to determine the individual variation and group dynamics in sheep subjected to VF technology***. An experiment was designed that looked at the individual variation and group dynamics of a small flock of sheep in a normal paddock, as well as in response to a virtual fence. The results showed that it took an average of 3-7 interactions with the virtual fence for learning to occur in sheep. The results also showed that naïve sheep exposed to the virtual fence as a group have a low probability of receiving an electrical stimulus which was in sharp contrast to the results of naïve sheep trained <u>individually</u> where 60-99% sheep received the electrical stimulus. The results also showed that the sheep's temperament did not affect their interaction with the virtual fence or proportions of electrical stimuli received. As with previous group studies, interactions with the fence were often affected by surrounding sheep, with sheep in the front of the flock receiving an audio or electrical stimulus turning other sheep around and away from the fence. The results of a complementary experiment conducted by Dr Rick Llewellyn from CSIRO suggested that at least 66% of sheep require neckbands capable of delivering the appropriate cues for virtual fencing.
KPI 8.2	Provide an update on field experiments that use VF technology to restrict movement of sheep to improve pasture utilisation (Output 7(d)).	***Output 7(d) – Conduct field experiments to determine the effectiveness of VF technology to restrict movement of sheep to improve pasture utilisation, including detailed assessment of any effects on animal welfare status of the animals.*** An experiment investigated the implementation of VH technology in pasture management, using a small group of sheep. During the trial, the sheep were allowed to graze for a period of 4 hrs during the day. The time period was limited due to labour requirement in implementing the virtual fence manually. The sheep were constrained to the pasture allocation area by either a virtual fence or an electric fence. Similar amounts of pasture were consumed during the 4-hour grazing period. Furthermore, there were no differences in the amount of grazing that occurred at the fence line for both the groups. All animals in the virtual fence treatment were effectively contained within their paddock during the 4-hour grazing period. There was no effect of treatment on behavioural welfare measurements and the average proportion of electrical stimulus to audio cues was 12% which is below the benchmark of 20% of the total cues being the electric stimuli.
KPI 9.6	Provide a final account that summarises the identification of opportunities for labour savings through the	***Output 7(e) – Conduct field experiments to determine the effectiveness of VF technology to encourage movement of sheep in practices such as mustering, including detailed assessment of any effects on animal welfare status of the animals.***

	application of VF in sheep wool and meat enterprises, incorporating the results of final studies that investigate the use of VF technology for mustering (Output 7(e)).	**Determine the effectiveness of VH technology to encourage movement of sheep in practices such as mustering.** In a sheep herding study, two groups of 6 sheep each were herded across a paddock (approximately 140 m x 80 m) using the single back fence method in which a single virtual fence sequentially followed behind the animals as they moved down the paddock. The results showed that sheep were able to be herded down the paddock and they took between 10 and 60 minutes to get to the end of the paddock, depending upon the flock's motivation to move. Furthermore, if one sheep in the flock of six initiated movement then the remaining sheep tended to follow and reached the end of the paddock more quickly. **Assessment on animal welfare status.** Much of this work to examine the effect of VH technology delivered by manual cues on the subsequent welfare status of sheep was conducted as part of PhD studies conducted by Ms Tellisa Kearton. In order to optimise the likelihood of successful implementation, it was important to understand whether the use of audio cues ("beep") and electric stimuli that are an integral part of VH technology had any welfare impacts on the animals. A study was conducted to compare the impact of the audio cue and the electrical stimulus with known stressors in sheep, these being dog barking and restraint. During the trial, 80 Merino ewes were assigned to either of five treatments; control, beep, dog bark, restraint or electrical stimulus treatments. Ranking of the least to most aversive treatments taking into account behavioural and physiological measurements were: Control< Beep<Barking Dog< Electrical stimulus < Restraint. These results show that any impacts on animal welfare of the audio and electrical cues used in VH technology were considerably less than simple constraint of the sheep. A second study investigated the stress responses of sheep that were trained to the virtual fence using correct training techniques, compared to poor training techniques. When sheep are correctly trained to the virtual fence they learn to react to the audio warning and avoid receiving the subsequent electrical stimulus. This provides predictability (the audio warning) and controllability (avoiding the electrical stimulus by stopping or turning around) of their interaction with the virtual fence. Having good predictability and controllability is an important aspect of virtual fencing that ensures acceptable welfare status of the animals is maintained.
KPI 10.6	Provide a final account that summarises the identification of opportunities for labour savings through the application of VH in sheep wool and meat enterprises, incorporating the	***Output 7(e) – Conduct field experiments to determine the effectiveness of VF technology to encourage movement of sheep in practices such as mustering, including detailed assessment of any effects on animal welfare status of the animals.*** The final account of the identification of opportunities for labour saving in the sheep industries is provided in Section 3 of this Final Report under Subprogram 4.

	results of final studies that investigate the use of VH technology for mustering (Output 7(e)).	
Activity B8	**Identify considerations and challenges for integration and adoption of virtual fencing.**	
KPI 4.3	Advise the Department of the outcome of the farmer and advisor workshops (Output 8a)	***Output 8(a) Conduct cross-sectoral workshops to identify key considerations for adoption of Virtual Fencing technology for the farmer and advisor sectors of each of the livestock industries.*** Four producer-based workshops that separately involved the dairy, sheep/cropping and both intensive and extensive beef production industries were conducted. The designed workshop process captured the opportunities, challenges and uncertainties involved with adopting VH technology from the perspectives of livestock producers. Another four workshops were conducted in 2018 to explore the extension role of potential providers (agricultural advisory sector, NRM organisations and state government public sector) as additional contributions to Output 8(a). There were additional stakeholder engagement meetings during 2019 with a selected processor and two food companies. The accumulated findings from the discussions amongst stakeholders across the value chain informed the key activity in 2020 – the identification of an adoption pathway(s) for virtual herding technology through the facilitation of a cross-sectoral workshop with all stakeholders across the supply chain.
KPI 6.4	Provide an update on the progress of identifying challenges for integration of VF on farms, and an assessment of costs and benefits (Output 8(b).	***Output 8(b) – Conduct dairy, sheep and beef farm case studies to identify challenges for integration on-farm, to assess costs and benefits and the value of on-farm VF technology to different stakeholders.*** The cost-benefit analysis of implementation of VH technology on-farm had been deliberately delayed to the final 2 years of the project, so that it can be based on a sound understanding of what the technology can and cannot do. A partial budgeting approach was used to understanding the cost of implementation of VH on farm and the anticipated benefits (including agricultural production, farm work organisation, environmental and lifestyle).
KPI 8.3	Provide an update on the completed case studies (Output 8(c)).	***Output 8(c) – Document completed case studies to provide cost benefit of various applications of VF technology to the different livestock industries, and compare them to previous cost benefit analyses provided by industry.***

		The project team at The University of Melbourne investigated the break-even cost that farm businesses could invest in VH technology based on anticipated benefits. They conducted benefit cost analyses for 3 livestock production systems; pasture based dairy, extensive beef grazing and a mixed farm system comprising sheep and beef production. The dairy farm had 680 cows and was located in West Gippsland. The results of the BCA indicate that if the VH technology is used to split daily pasture allocation to enable later milked cows to have access to a greater quantity and higher quality of pasture then the maximum the farmer could pay $238 per cow for the technology. Whereas the break-even cost was only $77/cow for either, reduced pugging damage with more flexible grazing or fetching cows for milking to save labour and vehicle use. The sheep/beef farm was in Western Victoria and had over 10,000 sheep on the home farm and about 2,300 cattle on two out-blocks. The results of the BCA indicate that the investment in VH technology on out-blocks to manage beef cattle appeared to be worthwhile, but it did not appear to be for sheep even when multiple benefits are combined. While the break-even cost of using VH technology to save labour and control grazing was about $400/cow, any use of VH technology with sheep to either, improve pasture utilisation, increase lamb survival or manage riparian zones was less than $100/ewe. The beef case study farm was a breeder operation in central, western Queensland and contained 400 breeders and their progeny. The results of the BCA indicate that if VH technology was used to assist in mustering the herd for branding and weaning, then the maximum the farmer could pay was $35/cow. However, the break-even cost of improving the carrying capacity by 20% through better pasture utilisation was $255 for each cow. Obviously, costs and benefits will vary for individual farm businesses but the results of these Benefit Cost Analyses indicated that labour savings alone were not enough to achieve break-even costs in a realistic range. Productivity gains on beef and dairy farms were essential to achieving realistic break-even costs. In addition to productivity improvements, there will also be opportunities for improved environmental outcomes. Adoption of VH technology in sheep production systems does not appear to be profitable at present because of the large number of neckbands required.
KPI 9.7	Provide a final account on the adoption pathway(s) for implementation of VF technology in the livestock industries, incorporating the results of final workshops (Outputs 8(d) and 8(e)).	***Output 8(d) – Conduct a cross-sectoral workshop with stakeholders to develop a coordinated plan across the livestock industries to realise benefits and address identified challenges.*** A cross-sectoral workshop with stakeholders was planned to be held between March and August, 2020. However this workshop could not go ahead because of the COVID19 pandemic. As an alternative a Consultative Panel was established to develop a strategy for the successful adoption of VH technology by the livestock industries. The 12-person Consultative Panel comprised a wide range of people

		representing progressive farmers, RDCs, Agricultural consultants, technical people from key R&D providers and a representative of Agersens. These people were sent a comprehensive briefing paper and then engaged in a 2 hour Zoom meeting on 22nd September, 2020 to discuss the adoption of VH technology. The key messages from the discussion with the Consultative Panel were: • VHT is a complex technology and therefore requires significant adoption support • The Generic Transfer of Technology model is not enough but a multi-approach was required. • Adoption pathway needs to be adaptive with a level of customisation built in • Value proposition for the technology needs to be better defining and refining • Adoption pathway may need to be multi-staged. ***Output 8(e) – Define and document the adoption pathway(s) for implementation of VF technology in the livestock industries.*** The culmination of the extensive engagement with all sectors of the livestock industries through the supply chain from producers to retailers was the development of an adoption strategy for VH technology. The complete strategy document is provided in this Final Report as Appendix 7.5. The purpose of the Virtual Herding Technology Adoption Strategy was to provide the context for adoption, suggested pathways for beef, dairy and sheep/mixed production industries and present a set of final recommendations that set out the roles and responsibilities for the governance of VHT adoption. The adoption pathways for the respective livestock industries aim to build capabilities in VH technology applications while increasing support for adoption over time to ensure end-users make informed decisions about this exciting innovation.
KPI 10.7	Provide a final account on the adoption pathway(s) for implementation of VH technology in the livestock industries, incorporating the results of final workshops (Outputs 8(d) and 8(e)).	***Output 8(d) – Conduct a cross-sectoral workshop with stakeholders to develop a coordinated plan across the livestock industries to realise benefits and address identified challenges.*** ***Output 8(e) – Define and document the adoption pathway(s) for implementation of VF technology in the livestock industries.*** The final account of the identification of adoption pathways is provided in this Final report as Appendix 7.5 "Virtual Herding technology adoption strategy".

3.2 Contribution to programme objectives

Virtual herding/fencing technology is an innovative technology that eliminates the disadvantages and barriers to adoption of conventional fencing systems. The objective of the project was to deliver significant (10 to 20%) productivity and profitability improvements for livestock enterprises through evaluation, demonstration and participatory adoption of virtual herding and fencing technology.

While several of the experiments conducted in this Project were able to demonstrate significant improvements in productivity or environmental outcomes, more widespread field experiments involving larger numbers of animals were not able to be carried out because of initial delays in access to the pre-commercial prototype from Agersens as well as the impact of the COVID-19 pandemic towards the end of the Project. However, with the impending launch of the commercial product, eShepherd® by Agersens and Gallagher in early 2021, there will be opportunity to examine the likely productivity and environmental improvements through the use of the VH technology on large numbers of animals and across several farms in the extensive cattle grazing industry in Queensland.

Despite extensive quantitative data on productivity improvements not being available during the course of this Project, case studies of experiments within the Project and subsequent benefit cost analyses have shown that conservative improvements of about 10% in productivity arising after the implementation of VH technology would be sufficient to justify the cost of neckbands on all animals in the herd and the installation of the infrastructure associated with VH technology. In fact, the cost of the neckbands (which is the main cost associated with the technology) will be well within the range of comparable activity collars.

The analyses reported by the project suggest that labour savings alone were not enough to achieve break-even costs of implementation of the technology on farms. Pasture or livestock production gains were essential to achieving more realistic break-even costs. Most of Australian livestock systems, particularly beef and sheep, are stocked well below their productive capacity with these livestock typically consuming only 40 to 50% of feed grown, while the dairy industry achieves at least 70% of grown pasture utilised. The use of VH technology offers an achievable pathway to increase consumption of home grown feed by at least 10% through better control of grazing, thereby achieving economic improvements in productivity and profitability for the Australian livestock industries. In addition to the productivity gains, there are opportunities for improved environmental outcomes, for example through better management of treed and riparian areas without need for permanent fencing.

The Project also investigated the learning, management and ethical/moral challenges associated with the adoption of VH technology on farm and some of the barriers to adoption of this new technology. Learning challenges relate to developing new skills, adapting systems on farm and the availability and quality of advice. The management challenges explored in the Project included understanding the costs and benefits of VH technology as well as the need to train employees. The final outcome was the development of an adoption pathway for VH technology that will involve a level of customisation for each livestock industry (beef, dairy and sheep).

Throughout the Project there was collaboration between the research and development industry organisations, Dairy Australia, Meat and Livestock Australia, Australian Wool Innovation and Australian Pork Limited to identify potential applications of the technology to the respective livestock industries. In the case of AWI and APL, it was accepted that the Project was unlikely to deliver industry outcomes directly to the pork and wool industries. The Project team and Agersens identified that the initial market for the technology was likely to be the extensive northern beef industry where the productivity gains from commercial implementation of the technology were going to be greatest. It is likely that MLA will continue to support the adoption of VH technology for the northern beef industry as well as initiate further research into this area.

4 Collaboration

The Project was also extremely successful in facilitating collaboration between the research providers within this Project and establishing long term relationships between these groups. The R&D providers that contributed to this Project included CSIRO, University of Melbourne, University of Sydney, University of Tasmania and University of New England. The Project established significant research capability in animal welfare and implementation of new technology with the recruitment of four post doctoral fellows, a research fellow and two postgraduate students to the project. This capability may be utilised beyond the scope of the Project as virtual herding technology becomes commercially available to the Australian livestock industries. Already, teams at CSIRO and University of New England have been successful in attracting R&D funds from Australian Wool Innovation and Grains Research and Development Corporation to further investigate the application of technology to the wool industry.

A strong relationship was established between the Project team and the commercial partner in the Project, Agersens Pty Ltd, through formal Agreements between 3 of the R&D providers (University of Sydney, CSIRO and University of Tasmania) and Agersens for the use of the pre-commercial prototype used in experiments in the Project. These agreements allowed discussion about the use of the technology between Project partners, but excluded any further discussion with organisations outside the Project. There was substantial interest in the Project activities from other R&D providers such as Agriculture Victoria, Central Queensland University, University of Western Australia and AgResearch in New Zealand, but the binding Agreement between Agersens and the respective R&D providers did not allow further collaboration or information sharing during the Project. However, it is likely that at least a couple of these other R&D providers may initiate further work to evaluate VH technology for various uses in the livestock industries.

The research team was able to provide worthwhile feedback to Agersens during the development and commercialisation of the technology that identified gaps in knowledge about the potential uses of the technology as well as a thorough assessment of the welfare status of animals that were exposed to the technology. The information that was generated by the Project on the physiological and behavioural response to the technology has been extremely useful in discussions with State Governments to allow the technology to be used commercially in Queensland and Tasmania and for experimental purposes in the other States.

5 Extension and adoption activities

Much of the interaction of the Project Team with the livestock industries in Australia was to create awareness of the VH technology and what the potential was if applied to Australian agriculture.

The Project created substantial interest in this new technology right from the start of the Project. Very early on, a Farmer Panel comprising about 25 progressive livestock producers was established. In addition, a series of focus groups and meetings were conducted across the livestock value chain (beef, dairy and sheep producers, agricultural advisers, natural resource management organisations, food processor, food retailers and state government departments) which enabled a range of stakeholders to become familiar with the concept of VH technology, have direct contact with the commercial developer and a forum to raise any concerns and opportunities for the adoption and implementation of VH technology. Regular Newsletters and webinars were conducted throughout the Project that presented some of the results of the research and how the technology could be applied to the livestock industries. As a result a database of almost 200 people that expressed a genuine interest in the technology was established, which culminated in over 160 people being registered for the final webinar held on 17th September, 2020 which presented the main findings from the Project and the implications for the livestock industries in Australia.

Each of the major livestock industries has extensive regional extension networks around Australia and members of the Project Team were able to tap into these networks to create awareness of the VH technology and encourage discussion and interaction with the Project Team. A list of most of the interactions between members of the Project Team and industry and the farming community is provided in Appendix 7.1. These interactions range from presentations in most States to farmer groups associated with the dairy beef and cattle industries, presentations at industry seminars and conferences, media articles, radio interviews and nine Project Newsletters that were widely distributed. These activities certainly created a great deal of interest amongst the farming community and land managers.

Significantly less attention was made to provide information to the livestock industries about the technology after this initial awareness strategy. There was some delay in Agersens being able to provide a commercial product that would satisfy the requirements of farmers in the northern cattle industry. Furthermore it became obvious that a commercial product would not be available to the dairy and southern beef industries until after the completion of the Project and a product suitable for sheep would not be developed for at least another 5 years. The pausing of a wide range of awareness activities was deliberate to temper any enthusiasm and expectations from the livestock industries of any impending release of a commercial product that would be tailored to their needs.

The development and release of the commercial product, eShepherd®, was not completed within the term of this Project. Any extension program together with associated activities to facilitate the adoption of the technology will be developed by Agersens (https://www.agersens.com/) and their international distributors, Gallagher (https://am.gallagher.com/en-au), from 2021 onwards. The beef industry in northern Australia is the initial target market and Meat and Livestock Australia are likely to support any extension activities with this sector of the beef industry. Extension activities in the dairy and southern beef industries are unlikely to be developed until the technology has been successfully implemented on Queensland beef farms and until legislation and regulations change in the southern States which would allow the commercial use of the technology for these industries. This is likely to occur within 1-2 years.

6 Lessons learnt

Many of the challenges and lessons learnt in this Project were identified in the Milestone Reports that were regularly submitted during the course of the Project. The main issues included:

- The time between official announcement that the Project received support from the Rural R&D for Profit program (1 July, 2016) and when the Project was supposed to commence (also 1 July, 2016) allowed no time to engage with the R&D providers to start the process of appointing staff to the Project. Consequently, all partners struggled to advertise, recruit and appoint key staff to the Project within 5-6 months of the start of the Project. Ideally the announcement of successful projects and subsequent funding should be made at least 2-3 months before the Project is due to start.
- Projects like this one that involve the use of new technology where there may be established IP arrangements, do require much more legal input and negotiation with Project Partners before the Project Management Agreement can be finalized. The Project Management Agreement between Dairy Australia and the 9 Project Partners was finally executed and signed on 13th April, 2017 after much negotiation between Dairy Australia and some of the Project Partners, mainly around IP issues relating to the RDCs and the Universities. Consequently this has led to tension about appointment of staff and starting experimental activities without a signed Agreement in place. The subsequent delays were hard to anticipate at the outset of the Project and even if there was a longer lead-in time, there is still likely to be delays in signing a suitable Project Management Agreement. But overall, during the development and establishment of this Project, the collaborative and cooperative nature of the key staff at each of the R&D providers (TIA, U Syd, UNE, CSIRO and U Melb.) and the commercial company that has licensed the VH technology (Agersens) enabled the Project to get underway with minimal delay and disruption.
- Many of the experiments planned in this Project were dependent upon using appropriate pre-commercial prototypes of eShepherd® that were to be supplied by Agersens. The development of these prototypes was delayed due to complicated issues around power supply, GPS accuracy and adequate attachment to different types of animals. However, this delay was, in part, anticipated and the activities in the Project were not unduly affected as there were contingency plans to use manual collars (particularly for the sheep work and the more basic cattle studies) and simulation type studies, which mimicked the application of the Virtual Herding technology. But there was some delay in achieving some milestones but these were still successfully achieved within several months of the due date.
- In addition to the delay in supply of the prototypes, the costs of suitable VH devices were considerably more than what each of the Partner R&D organizations originally budgeted for. Fortunately, the interest earned on the funds invested was able to be used to contribute towards the infrastructure required and purchase of suitable VH devices to be used in the animal studies at Armidale, Elliot and Camden.
- The Project was fortunate that the 5 key staff and 2 postgraduate students that were appointed to the Project remained committed for the whole 4 years of the Project. One of

the Project Leaders did take about 6 months maternity leave during the Project, but a suitable replacement was appointed for the period of maternity leave.

- What we have learnt from this Project is that an amount should be budgeted for and set aside for contingencies, as things come up in Projects that are not envisaged, such as greater costs of critical equipment and any delays due to changes of critical staff.
- There was continued interest by other R&D agencies outside those in the Rural R&D for Profit Project to undertake research into various application of the virtual herding technology to the livestock industries. As the R&D partners in this Project were constrained by IP clauses in the contract and non-disclosure agreements with Agersens, the R&D partners in this Project could not actively encourage collaboration in R&D.
- The activities and presentations from the Project staff created sufficient awareness of the Project and VH technology amongst the livestock industries and associated Stakeholders. However further extension efforts to promote the use of VH technology by industry were constrained by the availability of a commercial version of the eShepherd® technology. Project staff did not want to stimulate undue enthusiasm for the new technology when it wasn't commercially available. The first commercial release by Agersens of the eShepherd® technology has been delayed a couple of times and it is now due for controlled commercial release to the northern beef cattle industry in Queensland in early 2021.
- Presently the eShepherd® technology can only be used commercially in Queensland and Tasmania. However, information from this Project on any animal welfare implications of using the technology is being used to help convince the relevant Government Department in other States to allow the technology to be used commercially. These discussions between Project Partners and various State Governments will continue beyond the end of the Project.

7 Appendix - additional project information

7.1 Project, media and communications material and intellectual property

The list of project communications below includes a large number of research papers that have been published in scientific journals and at conferences between 2017 and October, 2020. In addition there is a list of industry publications, newsletters and media articles arising during the period covered by the project. Many high resolution photographs and figures have been included in Project Newsletters and the series of Technotes that have been produced by the Project. These photographs along with caption and credit information can be made available to DAWE if required.

The Intellectual Property of the virtual herding technology arose out of two patents that were granted in Australia several years ago. They were:

- Australian Patent 2005 263181: "An apparatus and method for the virtual fencing of an animal", and
- Australian Patent 2008 903820 "A control device, and method, for controlling the location of an animal".

Subsequently Agersens Pty Ltd negotiated an exclusive licence with CSIRO in 2015 to commercialise the virtual herding technology that is patented by CSIRO. In addition, any IP that may have been generated by some of the R&D Providers using the pre-commercial prototype version of the automated eShepherd system was covered by individual Agreements between the three R&D providers (University of Sydney, CSIRO and University of Tasmania) and Agersens for the use of the eShepherd system. These Agreements stipulate that these R&D providers had no right in the VH technology, nor any improvements and any novel IP generated was owned by Agersens as part of these individual Agreements.

Any IP that was generated using the manual neckbands was covered by the DAWE Project Agreement with Dairy Australia (as Project Manager). Dairy Australia is more interested in getting the technology adopted by industry and has freely offered any UP arising from the use of the manual neckbands to Agersens. However, no relevant IP has been identified by either party.

List of Publications (October, 2020)

Scientific Publications and Conferences:

Campbell, DLM, Lea, JM, Farrer, WJ, Haynes, SJ, and Lee, C (2017). Tech-savvy beef cattle? How heifers respond to moving virtual fence lines. *Animals,* 7, 72-83.

Campbell, DLM, Lea, JM, Farrer, WJ, Haynes, SJ, and Lee, C (2017). Commercialising an automated GPS-based virtual fencing system for livestock. *Proceedings of the 7th International Conference on the Assessment of Animal Welfare at Farm and Group Level, 5-8 September, De ReeHorst, The Netherlands.* Page, 232.

Marini, D, Meuleman, D, Belson, S, Rodenburg, B, and Lee, C (2017). Development of an ethical virtual fencing system for sheep. *Proceedings of the 51st Congress of the International Society for Applied Ethology, 7-10 August, 2017, Aarhus, Denmark.* Page, 159.

Lomax, S, Colusso, P, Gargulio, J, and Clark, C. (2017). Determining learning and behavioural response to a virtual fence for dairy cows. *European Conference on Precision Livestock Farming EC-PLF, 12th-14th September, 2017, Nantes, France.*

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Lomax, S., Colusso, P, and Clark, CEF (2018). Making virtual fencing work for individual dairy cattle. *Australian Dairy Science Symposium, 21-23 November, 2018. Palmerston North, New Zealand.*

Latham, K (2019). Virtual fences to improve labour efficiency for farmers. Appears in the January, 2019 issue of "The Farmer" produced by NSW Farmers and shown at: https://www.nswfarmers.org.au/NSWFA/Posts/The_Farmer/Innovation/Virtual_fences_to_improve_labour_efficiency_for_farmers.aspx

Verdon M and Langworthy, A. (2019). Investigate virtual herding technology to improve dairy grazing management. *Twelfth Annual Tasmanian Dairy Conference,* Launceston Country Club, Tasmania, 21 March, 2019

Colusso, P, Clark, C and Lomax, S (2019): Individual versus group response to and learning of virtual fence. *Australasian Dairy Conference Young scientist competition*. Canberra, 19-21st February 2019.

Marini D (2019) Research update: Application of virtual herding technology on sheep. Proceedings of AVA Annual Conference, Perth, 5-10th May. Pg 434- 435 https://www.ava.com.au/siteassets/conference/ava-conference/proceedings/proceedings-of-the-ava-annual-conference-perth-2019.pdf

Marini D (2019) Virtual Fencing. Presentation at MerinoLink Conference 20th June at CSIRO "Chiswick" Armidale.

Campbell DLM and Lee C (2019). Development of a virtual fencing system for cattle. Presentation to producers as part of the Pasture Update field day, hosted by GSSA and BIGG, Barossa, SA, June 18, 2019.

Colusso, P, Clark, C and Lomax, S (2019) Dairy cattle response to and learning of a virtual fence: Individual and herd**.** *Dairy Research Foundation Symposium Emerging scientist competition.* Bega, 10-11th July 2019.

Lee, C (2019) Virtual herding for cattle and sheep. The 9th National Animal Welfare RD&E Forum, The University of Melbourne, Parkville. 6th November 2019.

Colusso, P, Clark, C and Lomax, S (2020) Can a virtual fence restrict dairy cows from fresh pasture. Dairy Research Foundation Symposium, Camden, NSW. 22nd July 2020.

King, RH. (2020). Enhancing the profitability and productivity of livestock farming through virtual herding technology. Webinar from University of Sydney, 17th September, 2020. https://youtu.be/xa22fP6_k8Q or https://www.dairyaustralia.com.au/resource-repository/2020/10/25/virtual-herding-project-webinar#.X5Y-REfivIU

Newsletters

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 1. May, 2017.

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 2. September, 2017.

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 3. February, 2018.

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 4. July, 2018.

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 5. November, 2018.

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 6. March, 2019.

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 7. July, 2019.

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 8. November, 2019.

Virtual Herding Research Update – Enhancing the profitability and productivity of livestock farming. Issue 9. April, 2020.

Media articles

As a result of the CSIRO blog on Virtual Herding (https://blog.csiro.au/turns-can-teach-old-young-cows-new-tricks/) that was distributed in August, 2017, several media outlets picked up the story and ran articles. These included:

- An extensive article in Beef Central at: https://www.beefcentral.com/production/nsw-virtual-fencing-trial-shows-promise-in-commercial-cattle-application/.
- Rural Weekly: https://www.ruralweekly.com.au/news/cows-adapt-smartly-to-virtual-fencing/3211260/.
- A radio interview with Dana Campbell from CSIRO appeared on 2GB 873AM radio. https://www.2gb.com/podcast/virtual-fences/

An interview of Sabrina Lomax from University of Sydney appeared on ABC Rural News during August, 2017. See: http://www.abc.net.au/news/rural/2017-08-08/dairy-farmers-keep-close-eye-virtual-fencing-project/8784956.

An interview of Megan Verdon from Tasmanian Institute of Agriculture appeared on Tasmanian Country Hour on 27th February, 2018. See: http://www.abc.net.au/radio/programs/tas-country-hour/tas-country-hour/9468736. and it starts at 41:40 and ends at 46:50

News article by Megan Verdon. Virtual fences, real benefits. Tasmanian Country. March 16th, 2018. Pg. 28. http://tascountry.realviewtechnologies.com/?iid=158321#folio=28

An interview of Megan Verdon with Libby Price on Country Today, "Virtual fencing for dairy cows", 23rd April 2018. See: https://soundcloud.com/user-895414954/virtual-fencing-for-dairy-cows?utm_source=soundcloud&utm_campaign=share&utm_medium=facebook

An interview by Megan Verdon for Triple J Hack, "Global positioning cattle-lite: how GPS can be used in farming, Monday 14 May, 2018. See: http://www.abc.net.au/triplej/programs/hack/virtual-herding-of-cattle-is-on-the-cusp-of-happening/9753196

Interview of Danila Marini for University of New England "Connect" 4th March 2019. Also posted to University of New England, AU Facebook page. See: https://www.une.edu.au/connect/news/2019/03/sheep-welfare-at-heart

Campbell D (2020) News article: https://www.stockjournal.com.au/story/6940938/study-highlights-virtual-fencing-possibilities/

7.2 Equipment and assets

There weren't any capital items purchased for the Project during the term of the Project. The major piece(s) of equipment bought specifically for the Project were 150 pre-commercial prototypes of the eShepherd® virtual herding devices from the Project partner, Agersens. These devices were about $600 each and were used successfully in these animal studies at Camden (n=60), Armidale (n=30) and Burnie (n=60) between 2008 and 2020. Since 2020, the VH technology has been further developed and these 150 devices do not operate under the new IT environment that is being used in the rollout of commercial devices to industry in 2021. Thus these devices are now obsolete and have been returned to Agersens.

7.3 Evaluation report

Enhancing the profitability and productivity of livestock farming through virtual herding technology

Monitoring and Evaluation Framework

2016 to 2020

Framework for Evaluation and Monitoring the Project

<table>
<tr><th>Evaluation Level</th><th>Project Details</th><th>Performance Indicators and Measures</th><th>M&E Methods</th></tr>
<tr><td rowspan="2">Project Outcomes

Achievable within the life of the project for the respective Stakeholders</td><td>Farmers

Those directly involved in the Project through the Farmer Panel and involved in focus groups, BCA analyses and case studies. They will have a much greater understanding of VH technology and the potential application to improve productivity and reduce costs, through pasture utilisation, labour saving and environmental sustainability.

Those farmers that are not directly involved in the Project will have a greater awareness of how VH technology works what it may offer the livestock industries.</td><td>• Extent of changes in the understanding (and awareness) by participating farmers (and by farmers generally) of VH technology and its potential application to livestock systems.
• Farmers being informed about the limitations and challenges of using the VH technology for various applications.</td><td>• Feedback from participating farmers during the course of meetings and focus groups, throughout the Project, particularly in Subproject 5. Members of the focus groups will be surveyed before and after involvement in the Project.
• Case studies capturing influence of activities on changes.
• Awareness by the general farmer population may be measured by Webpage hits during the term of the Project.
• RDCs can capture awareness about the project and VH technology through their regular farmer surveys.</td></tr>
<tr><td colspan="3">Evidence:

• In the Evaluation Forms from the Producer Workshops, over 90% of the 31 Farmers who participated in the four Producer Workshops conducted in 2017 indicated that their awareness of VH technology had increased from attending the workshop; some participants revealed that they were starting at quite a low level of awareness (1-3 out of 10) yet after the workshop these same participants indicated that their level of awareness had shifted to 6 or above, out of 10. These farmers were supportive of the technology but they needed more “convincing’ evidence to prove the ROI; there is also an absence of accessible demonstrations on commercial farms in the local region to provide the know-how of setting up and using the technology and validate the tangible outcomes/benefits.
• An average of 10 farmers regularly registered and logged into each of the project Webinars. In addition, 44 farmers or agricultural consultants involved in the livestock industries logged into the final Project Webinar on 17th September, 2020.
• Information on virtual herding technology has appeared in many media articles, with RDC information and has been presented at industry conferences (see Publication List). Thus there has been extensive awareness by livestock farmers on the potential of the use of VH technology. However, as the commercialisation process was delayed somewhat by finance and COVID19 factors, the Project did not actively promote the technology to the general</td></tr>
</table>

Evaluation Level	Project Details	Performance Indicators and Measures	M&E Methods
	livestock industries as it now won't be available commercially until the first half of 2021. The R&D outcomes from this DAWE Project have helped identify some of the potential applications for this technology for the various livestock industries. • The webpage hits are presented later.		
	Animal Welfare agencies While RSPCA declined the invitation to sit on the project Steering Group, they have agreed to comment on the progress of the Project, and particularly discuss any effects of VH technology on animal welfare.	• RSPCA being informed about the animal welfare implications with the application of VH technology to a number of potential uses in the Australian livestock industries. • RSPCA being satisfied with the application of VH technology to some specific priority applications	• Regular meetings with the Scientific Officer, Livestock, RSPCA • Feedback from Focus groups in SP5. Focus groups will include representatives of animal welfare agencies, as well as environmental organisations.
	Evidence: • Senior RSPCA staff, including Melina Tensen, Scientific Officer, RSPCA, regularly log into the Project webinars. In addition informal discussions between Melina and senior Project Staff have been held during various animal welfare meetings during the course of the Project. • The Project has provided an excellent summary of the physiological and behavioural animal welfare responses to the VH technology in the Technical Note 2, (animal welfare response). • Several members of the Project Steering Group have had discussions with both State and Federal representatives on RSPCA and Animals Australia about the minor animal behavioural and physiological responses to VH technology while being used to improve productivity and environmental outcomes.		
	Rural Development Corporations The RDCs participating in the project will have better awareness and knowledge of the potential application of VH technology and increased engagement with their levy payers about new technology in their respective industries.	• Awareness and understanding of the limits to the application of VH technology. • Further investment by RDCs in VH and related technologies in future Projects. Evidence of direct involvement by RDC levy payers in the Project through Farmer panel and focus groups.	• Feedback from the RDC representative on the Steering Group through recording change in understanding through discussion and the minutes. • Web hits on the VH technology page on the respective RDC websites.

<table>
<tr><th>Evaluation Level</th><th>Project Details</th><th>Performance Indicators and Measures</th><th>M&E Methods</th></tr>
<tr><td rowspan="3"></td><td colspan="3">Evidence:
RDC representatives on the Project Steering Group, particularly MLA and AWI representatives have explored opportunities for funding further work with VH technology.
The presentation on VH technology by Nigel Tomkin in Esperance in June, 2016 generated interest from WA farmers, such that Mandy Curnow, DPIRD explored the potential for VH for sheep/grain farmers in WA. However, funding was not able to be obtained for further work.
Australian Wool Innovation has had discussion with Agersens and CSIRO about adapting the commercial eShepherd collar to sheep for R&D purposes because of the substantial potential benefits of VH technology in the sheep/cropping farming systems.
A small study supported by GRDC and AWI and led by Richard Llewellyn, CSIRO investigated the use of the VH technology to better manage grazing land for sheep.
Virtual fencing was raised by WALRC (WA Livestock Research Council) as a priority and MLA have been requested to work up a Terms of Reference for the 2020/21 annual investment call.
A proposal is before MLA to support the development of a general virtual livestock management communications strategy. At the end of this Project it is still unknown if there is MLA support.
Representatives of the RDCs, particularly MLA, offered to be part of the Consultative Panel to help develop adoption pathways for the VH technology as part of Subprogram 5.</td></tr>
<tr><td>Researchers

Researchers participating in this Project will have increased knowledge of the VH technology and develop knowledge on the successful application of the technology to livestock farming systems without compromising animal welfare. They will increasingly collaborate during the Project with other organisations involved in the Project. .</td><td>Identification of potential new applications of VH technology.
Novel ways of assessing the animal welfare status of livestock undergoing experimental studies with VH technology.
Collaborative experiments involving researchers and students across Institutes.
New R&D questions that may lead to new research or Projects that are initiated.</td><td>Feedback from individual researchers through informal discussion and Project Team meeting minutes.</td></tr>
<tr><td colspan="3">Evidence:
Appointment of PhD students:
Ms Tellisa Kearton started at UNE in September, 2017 to assess the welfare implications in sheep of various cues associated with the virtual herding technology. The progress of Tellisa is satisfactory and she should complete her PhD studies towards the end of 2020.</td></tr>
</table>

<table>
<tr><th>Evaluation Level</th><th>Project Details</th><th>Performance Indicators and Measures</th><th>M&E Methods</th></tr>
<tr><td rowspan="3"></td><td colspan="3">Ms Patricia Colusso started at the University of Sydney in January, 2018 to investigate training and learning cues in dairy cattle and how this may be used to control cattle location and movement in dairy milking systems. Again the progress of Patricia is satisfactory and completion of her PhD studies is expected in early 2021.
• The Project R&D providers have shared resources such as the neckband prototypes and experimental monitoring devices. In addition, individual R&D providers have completed some of the KPI's and Outputs that others had originally agreed to conduct. For example, CSIRO conducted the University of Sydney proposed work on applying VH technology to improve environmental outcomes, while University of Sydney explored the way VH technology may be used to separate animals.
• The Project Team worked collaboratively to identify novel ways of assessing the welfare status of livestock exposed to VH technology. The major behavioural and physiological measures that may be practically used to assess animal welfare were identified by the Project Team and have been expressed in the Technical Note 2 from the Project.
• AgResearch in New Zealand purchased 100 eShepherd collars for R&D purposes in late 2018 and have collaborated with Agersens and a commercial company in NZ to examine the use of the technology in cow/calf operations. AgResearch staff relied upon the Project team for the basic understanding of how the technology may be used. However Confidentiality Agreements prevented further collaboration between the Project team and AgResearch.
• Other R&D Providers such as Agriculture Victoria, University of WA and Central Queensland University approached the Project Team to discuss further collaborations, but the binding Agreements between the R&D providers in the Project and Agersens prevented any further collaborations. .</td></tr>
<tr><td>State Governments

Information generated by this Project will include the behavioural and physiological response of cattle and sheep to implementation of VH technology. This information will be subject to peer review and will be published in international scientific journals.</td><td>• Scientific publications that provide evidence of the effects of VH applications on animal welfare measures.
• Extent of change in the understanding by Government agencies of the application of VH technology.
• Changes in State legislation to allow VH technology to be implemented in a number of States in Australia.</td><td>• Feedback from Focus groups in SP5. Focus groups will include State Government representatives.
• Science based evidence generated by this Project that has been peer reviewed and shows that animal welfare is not compromised when VH technology is used for certain applications for the livestock industry.
• Interaction of Project Partners with staff in relevant Government agencies</td></tr>
<tr><td colspan="3">Evidence:

• The Queensland and Tasmanian State Governments allow the use of VH technology on commercial farms without restrictions.</td></tr>
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<table>
<tr><th>Evaluation Level</th><th>Project Details</th><th>Performance Indicators and Measures</th><th>M&E Methods</th></tr>
<tr><td rowspan="2"></td><td colspan="3">The SA Government granted exemption in 2017 for the use of the VH technology under experimental conditions for the CSIRO project, “Control tools and technology development”.
Through the course of the Project the Victorian and NSW Governments have also granted exemption of the use of VH technology for experimental uses. Further approaches have been made by the R&D partners in the Project, particularly Agersens and CSIRO to these State Governments to allow the use of VH technology for commercial use. Discussions between several of the Project Partners and State Governments in Western Australia and Northern Territory about commercial use of VH technology are very promising by October, 2020.
The Victorian Farmers Federation was provided with information about the VH technology in 2019 to assist them in lobbying the Victorian Government to allow the technology being used in Victoria.
Many of the scientific publications have generated information on the behavioural and physiological response to VH technology which has been conveyed to the State Governments as well as being included in Technical Note 2 from the Project.</td></tr>
<tr><td>Agersens Pty Ltd.

Agersens are the commercial partner in this Project that has purchased the rights to the CSIRO VH technology and are in the process of commercialising this technology for implementation to the livestock industries. Prototypes supplied by Agersens will be used in the R&D program and the results will be provided to Agersens to potentially improve the prototypes and also identify specific applications of the VH technology</td><td>Continued engagement and commitment by Agersens to responding to the results of new R&D from the Project.
Improvements in the VH devices that will extend the use of the technology but does not compromise animal welfare.</td><td>Regular collaboration and feedback with the Agersens technical team.
Regular feedback from Agersens about the progress of the R&D program in the Project.</td></tr>
<tr><td></td><td colspan="3">Evidence:
Regular bimonthly face to face meetings between key Agersens staff and the Project Manager ensured that Agersens and the Project Team were aware of their respective RD&E and commercial activities in VH technology.
Preparation of overall framework, which includes all experiments conducted by the DAWR project, AgResearch, Agersens and other organisations.
The two Business Development Managers at Agersens attended each of the 4 Producer Workshops and indicated that the workshops provided a great avenue to learn about the different way farmers perceive risk on farm from the adoption of VH technology and the diverse benefits that farmers envisage from using VH technology in their farming systems. In addition, they attended the Environmental Managers and Advisors/Consultants Workshops in 2018 and gained very valuable insights into who the support sectors were going to be and why/how they would support the adoption of VH technology.</td></tr>
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<table>
<tr><th>Evaluation Level</th><th>Project Details</th><th>Performance Indicators and Measures</th><th>M&E Methods</th></tr>
<tr><td></td><td colspan="3">Agreements for the supply and use of the pre-commercial prototypes of the neckbands were signed between Agersens and each of the R&D providers (CSIRO, UTAS and University of Sydney) that used these automated VH devices in their subsequent animal studies. Each of the three R&D providers paid Agersens commercial prices for the number of neckbands required for their respective experimental program (n=30 to 60).
A report on the Experiments that used the automated neckband supplied by Agersens was compiled and presented at each Steering Group meeting.
Many of the key scientific papers and presentations, webinars and Technical Notes that were prepared by the Project Team were reviewed by Agersens (Cameron Ralph, Sally Haynes and the senior Agersens team) before being approved for publication.</td></tr>
<tr><td rowspan="3">R&D Activities

Research, development and engagement activities to achieve outputs and impacts</td><td>R&D Activities in the Project.

Each of the five subprojects has defined objectives and outputs that have been outlined in the Project Agreements. Further detail of the R&D activities in each subproject, particularly over the first 18-24 months of the Project, are outlined in the Project Plan.</td><td>Acceptance of the Project Plan by DAWR
Interim results and findings from each subprogram provided regularly in the Milestone Reports.
At least one scientific publication per year from <u>each</u> of the five subprojects.
At least one joint publication/protocol each year of the Project.</td><td>Project documentation as detailed in the Project Plan.
Inclusion of key findings in the regular Milestone Reports.
Industry and Scientific publications arising out of the experimental work.
Evidence of collaboration through joint publications or proposals.</td></tr>
<tr><td colspan="3">Evidence:
The Project plan accepted by DAWR in August, 2017.
The key findings and progress against Key Performance Criteria and Outputs were included in each of the Milestone Reports submitted to DAWE.
Scientific publications: Up until October, 2020, 25 scientific papers that were produced by the Project were accepted and published in international Journals. In addition another 8 scientific papers have been prepared or have been submitted to international Journals awaiting acceptance. Further evidence of the collaboration between R&D groups within the project was revealed by the number of scientific publications that contained authors from at least one organisation approached about half of all the scientific publications.
Industry publications, conferences and presentations: Members of the Project Team were often requested to present the results of their work in VH to industry groups, particularly early in the Project. In the last year or so, the Project placed less emphasis on these activities as Agersens did not want to create unreasonable expectations with the livestock industries about the technology before the device was released for commercial use. As at October, 2020, nearly 40 presentations in the form of papers, presentations, articles or webinars were delivered to industry audiences.</td></tr>
<tr><td>Communication Activities</td><td>Increasing traffic to the VH website over the course of the Project.</td><td>Analytics from access to the VH webpages will be assessed every 6 months.</td></tr>
</table>

<table>
<tr><th>Evaluation Level</th><th>Project Details</th><th>Performance Indicators and Measures</th><th>M&E Methods</th></tr>
<tr><td rowspan="3"></td><td>The Communications and Extension Plan outlines how the outcomes from the Project will be communicated to the wide range of Stakeholders</td><td>• Increased engagement with farmers through access to RDC and other Facebook pages.</td><td>• Analysis of the number of Facebook followers from posting articles on the RDC pages</td></tr>
<tr><td colspan="3">Evidence:
• The Project webpages on the Dairy Australia website were established in February, 2017 and were updated at least annually. The Dairy Australia website was completely restructured in September, 2020 and contains the latest update which will include copies of the Newsletters, final webinar and a series of Technotes.
• The analytics of visits to the virtual herding webpages show that there was an initial burst of the number of visits after which visits declined a little. But there has been an increase in recent times. For the first complete 6 month period between July, 2017 and December, 2017, there were only 389 pages views with an average 2.20 minutes spent viewing each time. In the subsequent 6-month period there were 995 visits to the Virtual Herding webpages, with each visit being 4.19 minutes. Since then the average visits to the webpages has remained relatively stable with between 756 and 1016 visits, and an average of about 4.3 minutes for each visit and about 240 downloads during each 6 month period up until June, 2020.
• A Facebook page for the Project was not established because of the need for significant resources to maintain it. However, CSIRO produced an initial blog about the VH Project in late August, 2017. As a result, there were 62 items of media hits and tweets, with a potential audience reach of 418,685.
• The first Newsletter was produced in May, 2017. Promotion of this Newsletter was done through the Dairy Australia Facebook page and it reached 3,269 people through social media. This compares favourably with the usual 1,500-2,000 people from other Dairy Australia posts on Facebook. Subsequent Newsletter (n=9) were posted on the Dairy Australia VH webpages.
• Six webinars describing the progress of the R&D project were held between June, 2017 and February, 2019. A total of between 22 and 37 people registered for each these events with between 11 and 24 attending these webinars.
• A seventh and Final webinar was presented on 17th September and over 200 people registered for this event and 121 finally attended this Webinar with the majority staying on line for the whole 2 hours (https://www.dairyaustralia.com.au/resource-repository/2020/10/25/virtual-herding-project-webinar#.X5Y-REfivIU). All Subprogram Leaders were involved in this final webinar and presented their main findings from the Project and implications for the Australian livestock industries. During the webinar, there were 34 questions that were asked which were answered either live by the presenters or on-line. The YouTube link to the final Project webinar is available from the University of Sydney Dairy Research Foundation website as well as the Dairy Australia website. Within 10 days of the webinar being posted over 100 people accessed the link on-line.</td></tr>
<tr><td>Extension Activities</td><td>• More awareness and positive opinions of the potential use of VH in livestock farming.
• 3 e-newsletters per year.</td><td>• Feedback from representatives on the Farmer Panel.
• Feedback from the general farming community through Subproject 5.</td></tr>
</table>

Evaluation Level	Project Details	Performance Indicators and Measures	M&E Methods
	The Communications and Extension Plan identifies how the Project is going to engage with the livestock farming community.	• An interest (and understanding) of what VF technology may provide for the livestock industries. • Number of farmers who are registered to receive the Newsletter.	• Distribution of the regular e-Newsletter. • On line surveys of registered participants in the Project
	Evidence: • Nine newsletters were produced in May, 2017, September, 2017, February, 2018, July, 2018, November, 2018, February, 2019, July, 2019, and November, 2020. The initial mailing list was about 50 people and included members of the Project team and the Steering Group as well as about 25 farmers who were on the Farmer Panel. The numbers on the distribution list expanded over time as more people indicated an interest in VH and the Project. As a result, about 160 interested people received the later issues of this regular Newsletter about the activities in the Project. • Feedback from the four farmer workshops in Subprogram5 identified general enthusiasm from beef, sheep and dairy farmers for VH technology and the range of potential benefits to be gained. The benefits included improving livestock management, improving pasture management, better management of different land classes for environmental and ecological outcomes, enabling a flexible farming lifestyle, contributing towards the social sustainability of the livestock industries and reducing farming costs. • There was positive feedback from several of the attendees at the final Webinar. In addition over 30 questions were asked during this Webinar by members of the audience. • There was little actual extension of the results of the Project to the farming community because the commercial product was not available during the course of the Project. The commercial version of the eShepherd neckband is likely to be available and sold to extensive beef producers in Queensland in early 2021. Thus the main activities of the Project team were to create awareness of the VH technology amongst the stakeholders in the livestock industries.		
Project Management ***Underpinning structures and processes to guide and support activities and outputs***	**Steering Group** A Steering Group has been established to provide expert advice and direction for the R&D program in this Project. This Group will also advise on potential IP issues.	• Evidence of influence and actions taken by members as a result of participation in the Steering Group meetings. • Satisfaction by Steering Group members of the progress of the Project	• Project documentation of Steering Group composition, attendance at meetings, minutes and action items. • Feedback from individual Steering Group members through an annual survey.
	Evidence:		

<table>
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<tr><td rowspan="3"></td><td colspan="3">

- The Steering Group has met twice a year with Agenda, minutes and action items produced for each meeting. All Action Items identified were followed up and completed between Steering Group meetings. Most members of the Steering Group attended these meetings either in person or via teleconference facilities such as Skype, Zoom, etc. Because of COVID19 restrictions, the last Steering Group meeting held on 10th June, 2020 was conducted by video through the CSIRO system.
- The Steering Group supported the proposal that the Project Manager appointed by Dairy Australia continue in that job for the remainder of the Project. This support by the Steering Group made it easier for extending the annual consultancy contracts between the Project Manager and Dairy Australia.
- The Steering Group preferred that the design of the animal studies was better coordinated across the Project, and drafts of scientific papers were made available to members as they were submitted for publication.

  Prof Paul Hemsworth agreed to review the protocols and experimental design and methodology of all animal studies using the eShepherd collars to confirm that the experiments are well designed.

  All scientific papers and abstracts submitted to the Project Manager for approval were then distributed to members of the Steering Group, for their information only.
- The last Steering Group meeting was held in June, 2020 and feedback was positive. Several avenues for further funding for VH work were identified and these were going to be explored by some members of the Steering Group

</td></tr>
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Reports to DAWR

Milestone Reports detailing progress of the R&D activities are required to be submitted about every six months to DAWR at agreed times. In addition Financial Reports are required at annual intervals in August each year and at the end of the Project

</td><td>

- Submission of Milestone and Financial reports by the due date, unless there has been mitigating circumstances.
- Acceptance of Milestone and Financial reports.

</td><td>

- Project documentation compiled into the DAWR templates that is submitted at agreed times to DAWR
- Feedback from the DAWR Project Manager based upon Milestone Reports and informal meetings and discussions.

</td></tr>
<tr><td colspan="3">

Evidence:

- Milestone Reports were submitted on time in December, 2016, March, August and December, 2017, August, 2018, December, 2018, August, 2019, December, 2019 and May 2020. Each of these Reports were accepted by DAWE and complimentary comments included that the reports contained all the required evidence and were easy to read.
- Ray King, Project Manager, attended AgCatalyst at Melbourne Tennis Centre in August, 2018 and had informal discussions about the progress of the Project with DAWE staff during the conference.
- Ray King, Project Manager successfully requested a 6-month extension of the Project until the end of 2020, because the start of the Project was delayed by up to 6 months through the delays in the recruitment of suitable staff to lead the Subprograms.

</td></tr>
</table>

Evaluation Level	Project Details	Performance Indicators and Measures	M&E Methods
	Project Team Project team meetings will be held at opportune times amongst the key researchers from each of the R&D partners and Agersens to discuss progress of research plan and opportunities for collaboration and sharing resources to improve efficiency of the Project	• Conduct of experiments that efficiently utilise Project resources. • Common and standard measurement protocols. • Number of joint proposals and protocols.	• Experimental protocols distributed, discussed and agreed by members of the Project Team. • Information gained from the minutes of the regular formal and informal Project team meetings.
	Evidence: • Dr Caroline Lee presented a common measurement methodology of animal welfare assessment at the September, 2017 Steering Group meeting which was followed by all researchers in the future. These measures of welfare assessments were fine-tuned during the Project and resulted in accepted levels of animal response to the VH technology that are summarised in Technote 2. • Regular Project Team meetings were held via teleconference (every 2 months) and face to face (every 6 months) where results and upcoming protocols were discussed. Action Items were followed up and completed between these 2 monthly meetings. • Experimental protocols were presented at regular project team meetings and were then distributed to the Project Manager, Agersens and Prof Paul Hemsworth for further comment and subsequent approval. • The Project Manager met with technical representatives of Agersens every 2 months or so to discuss the progress of the R&D and further opportunities for collaboration with Agersens or other parties. • The key people from the Project, the five subprogram Leaders, continued to contribute to the Project up until November, 2020 and for the whole term of the Project. Thus there were little disruptions to staffing resources within the Project and certainly the conduct and results from this Project were enhanced by the continued employment of these key people.		
	Experimental Ethics All of the animal studies in this Project require approval from the Animal Experimental Ethics Committee at the respective research Institute.	• Approval by the Institute AEEC for each of the animal studies conducted in the Project. • Approval by HEAC for all the stakeholder focus groups and case studies in SP5.	• Preparation and submission of the AEEC form for each animal study. • Preparation of the HEAC application to cover R&D activities in SP5.

Evaluation Level	Project Details	Performance Indicators and Measures	M&E Methods
	The human studies (Case studies, focus groups, etc.) in SP5 also require approval from the University of Melbourne Human Ethics Advisory Committee.	• Satisfactorily deal with any issues that may arise from either the respective AAEC or HEAC	
	Evidence: • Animal Ethics approval was granted for each animal study at the respective Institute. • Human Ethics approval was granted by the Veterinary and Agricultural Sciences Human Ethics Advisory Group from the University of Melbourne for the 7 Workshop series, as well as the livestock industry case studies and the Consultative Group.. • The annual ethics report for both animal ethics and human ethics have been submitted by the respective R&D provider and subsequently accepted. • A list of the title, allocated number and approval date by the respective Animal Ethics committee was compiled for the benefit of the RDCs. This list comprised a total of 23 animal experiments (CSIRO, 6; UTAS, 8: University of Sydney, 2; and UNE, 7) conducted during the course of the Project.		
	Project management A Project Manager has been appointed by Dairy Australia to ensure that the outputs and desired outcomes of the Project as outlined in the Commonwealth Agreement with DAWR and in the Project management Agreement will be met over the 4-year term	• Reports submitted on time. • Agenda and Minutes prepared for the various meetings. • Satisfactory identification and subsequent response to issues that may arise during the Project. • Overall satisfaction by Dairy Australia and other key stakeholders	• Preparation and submission of Milestone and Financial reports to DAWR. • Coordination of Steering group, Farmer Panel and Project Team meetings. • Feedback survey sheets from the Project Partners
	Evidence: • The 9 Milestone Reports together with the Financial Reports for each year were submitted on time to DAWE. • The Steering Group met at least twice each year, while the Project Team met every 6-8 weeks during the 4 years of the Project to discuss progress of the Project. Notes from these meetings including identified action items were subsequently prepared and distributed. • The Farmer Panel was often used to identify livestock farmers to contribute to the Subprogram 5 workshops, suggest suitable case studies and for informal discussion about the progress of the Project and the commercialisation of the VH technology,		

Evaluation Level	Project Details	Performance Indicators and Measures	M&E Methods
	• The Steering Group endorsed and supported the appointment of Ray King as Project Manager from July 1, 2017 on the basis of annual contracts throughout the rest of the term of the Virtual Herding project. • The Project Manager has kept his time allocation and reimbursement expenses within the budgeted allowance for each of the financial years from 2016/17 until 2020/21, inclusive.		
Long term goal ***Enhancing the profitability and productivity of livestock farming through virtual herding technology.***	Increased returns on farms that may implement VH technology.	• Extent of changes in returns from implementation of VH technology for various applications on specific livestock farms. • Extent of changes in returns from implementation of VH technology on a population level across the various livestock industries in Australia.	• Benefit cost analyses of the implementation of VH technology tailored for particular livestock applications. • Case studies of adoption of VH technology in specific applications.
	Evidence: • Case studies of the application of the VH technology to three farming systems were developed as part of Subprogram 5. The price of VHT has yet to be established, so the approach taken in this study was to calculate the break-even cost per animal that the farm business could pay for the technology based on the anticipated benefits. Three case study farms were selected from leading livestock producers. These farmers had either had a pasture based dairy farm, mixed sheep/beef farm or an extensive beef production farm in Queensland. These case studies have shown that VHT can be profitably implemented on dairy and beef production systems with savings in the range $250-$400 per cow. Positive environmental outcomes were often identified as additional to the improvements in productivity. These savings are within the range of the cost of comparable activity collars. VHT in sheep production systems does not appear to be profitable because of the large number of neckbands required. Labour savings alone were not enough to achieve break-even costs in a realistic range. Pasture or livestock production gains were essential to achieving realistic break-even costs. The farmers identified that having other functions integrated with VHT, such as heat detection and animal health monitoring, would increase the likelihood of adoption. • Further benefit-cost analyses of the implementation of VHT on specific farms early in the commercialisation process will also be conducted by Agersens and will be part of their Marketing Plan.		

Evaluation Level	Project Details	Performance Indicators and Measures	M&E Methods
	Strong connections with the private sector that are commercialising VH technology for the livestock industries.	• Publication of guidelines on how to use VH technology on farms. • Improvements in the specific algorithms to improve the operation of VH technology. • Number of devices used by the livestock industries in Australia.	• Project Team members will prepare guidelines on how to use VH technology for specific application to livestock farming systems. • Make available any improvements in algorithms to the commercial entity. • Regular feedback from Agersens on the rate of uptake and use of VH devices by the Australian livestock industries.
	Evidence: • Training protocols have been established to teach animals the association between the audio cue and electrical pulse so that they remain in the inclusion zone the majority of the time. These training protocols have been based upon information obtained from the Project as well as observations in commercial trials by Agersens. As part of their Marketing strategy, Agersens will supply purchasers of the VH technology, detailed training protocols, as well as standard operating procedures for the day to day use of eShepherd. • The series of Technical Notes identify a number of applications of the VH technology to livestock production. They include applications to improve pasture utilisation, to herd animals, to control sub-herd livestock management and for environmental outcomes. • The algorithms have been extensively developed to include data from the Project and from commercial studies undertaken by Agersens. In addition to using the device for virtual fencing, there is potential to use the data to estimate time budgets and indices such as the duration of standing, lying, ruminating, walking, eating, etc. • With the COVID19 pandemic the commercial release by Agersens of the virtual herding technology known as eShepherdTM has been delayed, but it is expected that the technology will be available to the beef cattle industry in northern Australia by early 2021. Further information on the uptake and sales of eShepherdTM should be available later in 2021.		

7.4 Budget

The Financial Statement for financial year 2019/20 is included below in this Appendix. Financial Statements for the previous years of the Project (2016/17, 2017/18 and 2018/19) have been submitted in each August in Milestone Reports 3, 5 and 7 after the respective financial year. This 2019/20 Financial Statement indicates that the interest that Dairy Australia earned on the grant was a total of $59,607 for the duration of the Project.

The net balance at 30 June, 2020 is negative $225,073. Further expenses associated with Project Management and presentations of Webinar and Technical Notes are expected to be incurred towards the end of 2020 to successfully complete the Project. However a final payment of $260,000 due from DAWE in December, 2020 after this Final Report (Milestone 10) is submitted should cover this deficit. The Community Grants Hub Financial Declaration will be submitted by Dairy Australia before the end of January, 2021.

Dairy Australia

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Financial Statement of Income and Expenditure for the period from 01 July 2019 to 30 June 2020

Project Title:	Enhancing the profitability and productivity of livestock farming through virtual herding technology (15-02-019)
Grantor:	Department of Agriculture and Water Resources
Period	01/07/2019 - 30/06/2020

INCOME		
Grant income received from DAWR		300,000
Grant income received from DA		92,237
Grant income received from MLA		50,000
Grant income received from AWI		45,000
Grant income received from APL		5,000
Grant income received from TIA		45,000
Grant income received from University of Sydney		45,000
Grant income received from University of Melbourne		30,000
Grant income received from University of New England		15,000
Total Income for the reporting period		**627,237**
Total interest for the reporting period		**4,242**
In-kind		
DA		20,000
MLA		4,875
AWI		4,350
APL		2,500
TIA		98,252
University of Sydney		94,383
University of Melbourne		44,935
University of New England		21,575
Agersens		20,000
CSIRO		119,307
Total in-kind for the reporting period		**430,177**
EXPENDITURE		
Project Management consultant expense		40,618
Meeting expense		592
University of New England research		97,417
The University of Sydney research		157,500
University of Tasmania, Hobart research		193,259
The University of Melbourne research		133,278
CSIRO research		291,631
Total Expenditure for the reporting period		**914,295**
Carry forward from previous period		2,378
Project Balance at 30 June 2020	-	**284,680**
Project Balance at 30 June 2020 inclusive of all interest earned from grant income	-	**225,073**

I certify that:
a) income and expenditure as shown above is true and correct to the best of my knowledge.

Tina Lim
Financial Controller

1-Oct-20
Date

7.5 Virtual Herding technology adoption strategy

Australian Government

Department of Agriculture, Water and the Environment

VIRTUAL HERDING TECHNOLOGY ADOPTION STRATEGY

CO-DEVELOPED ADOPTION PATHWAYS FOR VIRTUAL HERDING TECHNOLOGY IN 2020

Abstract

The purpose of the Virtual Herding Technology Adoption Strategy is to provide the context for adoption, suggested pathways for beef, dairy and sheep/mixed production industries and present a set of final recommendations that set out the roles and responsibilities for the governance of VHT adoption.

Nikki Reichelt, Ruth Nettle, Brendan Cullen, and Gillian Hayman

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1. Context for VHT adoption

1.1 National approach to agricultural innovation adoption

Evidently there is a role for government and need for whole-sector support in adopting digital agriculture innovations. Virtual herding technology is no exception. The National Farmer's Federation has set a target to exceed $100 billion in farm gate output by 2030 (National Farmers Federation, 2018). The Australian Government is dedicated to reaching this target partly through leading the development of a digital agriculture strategy designed to achieve widespread uptake of digital technologies as a means to add value and efficiencies to farms, supply chains, regional communities and wider society (Australian Government, 2020a). Digital innovation for agriculture is a national priority evidenced by the building of a national vision for digital agriculture - Growing a Digital Future for Australian Agriculture, 2020.

The Australian Government is moving towards supporting digital agriculture as a joint venture. The Minister for Agriculture announced it is investing in the creation of a new entity, Agricultural Innovation Australia (AIA), to bring all 15 rural development corporations together for the purpose of collectively funding targeted transformational innovations in line with the National Agricultural Innovation Agenda (Australian Government, 2020b). The findings of an independent report authored by the Australian Council of Learned Academies' and commissioned by the Chief Scientist Dr Alan Finkel AO - The Future of Agricultural Technologies report - highlights the critical role of government in providing the regulatory environment for managing socio-ethical risks, backing programs in skills development and improving regional connectivity, while industry has an intermediary role between producers and technology developers to ensure high value is generated from innovation adoption (Lockie et al., 2019). Transitioning Australia's agricultural sector into a digitalised future is clearly a collaborative and national effort.

1.2 Background to VHT adoption

Virtual herding technology (VHT) is in its initial stages of commercialisation as a form of automated and digitised livestock management. The decision to adopt and apply this new technology is likely to require livestock farmers to navigate a range of opportunities, uncertainties, risks and complexities. In Australia, the commercial use of VHT is permitted in Queensland and Tasmania. Other states are considering changes to allow the commercial use of VHT.

The following VHT adoption pathways have been formed through a series of engagements with 67 stakeholders across the livestock value chain. In addition, 13 Agtech adoption experts have been consulted through written and verbal feedback to an extensive Discussion Paper based upon the findings from workshops and interviews that asked stakeholders to consider the opportunities and challenges with adopting VHT. Three possible approaches for enabling VHT adoption were identified from stakeholder and expert opinion:

1) The VHT adoption approach should include some form of governance to manage the perceived public concerns for animal welfare, social licence to operate and on-farm implementation risks. *(societal-driven)*
2) The VHT adoption approach should provide the commercial developer and livestock producer an unrestricted environment in which to access and experiment with VHT for innovation to thrive. *(market-driven)*
3) The VHT adoption approach should facilitate working collaborations between producers, advisers, researchers and the commercial developer as an ongoing learning and capability building network for co-developing the adoption pathways. *(customer support-driven)*

While there was no clear consensus about the best way to support the adoption of VHT, each approach has its merits and is integrated into the design principles and suggested VHT adoption pathways. Regardless of the approach, each adoption pathway needs to provide a dedicated role for science to inform what applications are valid as well as an acknowledgement of the animal behaviour elements of this technology. The implementation and outcomes of VHT is essentially a learning process that is reliant on developing an understanding of livestock responses to the virtual herding system for each herd.

1.3 Design principles for the VHT adoption pathways

These design principles guide the features and trajectory of the suggested adoption pathways for VHT.

$	Enhancing the commercial reality of virtual herding technology	While there is acknowledgement of the commercial route for VHT in terms of selling a product, there is scope to incorporate additional resources, support and participation from the industry, private and public sectors along the adoption pathway.
	Identifying the governance required	VHT adoption would benefit from some coordination, monitoring and guidance on best practices to manage and share the animal welfare and social risks as a responsible innovation.
	Enabling customer-driven adoption	Forming VHT Communities of Practice (CoP) could provide valuable support and learning to work through the complexities and enable the producer community to build capacity in assessing/trialing VHT alongside technical assistance.
	Customizing the pathway to respond to production diversity	The value proposition for adopting VHT is likely to vary according to livestock industry, production region, farming system, and producer attitudes. It needs to solve particular problems or generate specific advantages for each adopter.
	Building the value proposition	Since VHT is an emerging technology, there is a need to keep developing the business, production, environmental and social case for adoption through scientific and experiential evidence and economic analysis.
	Incorporating a degree of flexibility and adaptability	Approaches to VHT adoption are likely to change over space (no one approach will suit all adoption and application scenarios; extension and advisory capacity varies across Australia), and over time (technological functions and the value proposition may evolve from simple/single applications to more complex/multiple applications) therefore flexibility in approaches and resourcing should be enabled along the adoption pathway.

1.4 Time-sensitive adoption pathways for VHT

Prime target for initial adoption: The adoption pathway for the beef industry aims to build capabilities in assessing and applying virtual herding technology while increasing support for adoption over time to ensure end-users make informed decisions about this innovation (see Table 1). This pathway is likely to be actioned first considering the beef industry is the target market for the commercial developer. Over time, VHT for beef could eventually be offered as an 'adoption package' offering a suite of proven applications with a level of integration with other digital systems and technologies that are commonly used in the beef industry as well choosing different levels or options for support.

Prepare for adoption over the next 3 years: A similar adoption pathway has been suggested for the dairy industry. Rolling out the pathway over the next few years will allow for more testing in the field, production of new knowledge about the capability of the technology and greater insight into how it can be adapted for the dairy industry. Over time, VHT for dairy could eventually be offered as an 'adoption package' like beef.

Maintain interest over the decade: An adoption pathway for the sheep industry could follow the process proposed for beef and dairy, however this will be highly dependent on developing a VHT system specifically for sheep. Significant investment in R&D to design and trial a VHT prototype suitable for sheep is required. A commercial VHT product is unlikely to be available for adoption by the sheep industry for at least 5-10 years.

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2. Suggested adoption pathway – Beef Industry: prime target for initial adoption

VISION: to provide beef producers with enough evidence and support for making an informed decision about adopting virtual herding technology for their farming system.

Enabling VHT adoption at a policy level
State regulations: to permit commercial use in Victoria, NSW, ACT, South Australia, Western Australia and Northern Territory
Public education campaigns: to manage public perceptions and minimize misconceptions about VHT
National protocols: for ownership, access and use of on farm Big Data to ensure clear benefits for producers
Industry strategy: to improve the uptake of new technologies in the red meat industry (MLA Strategy 2025)

VHT adoption at the farm level (see Appendix 3 for more details about anticipated applications for VHT)
General applications: automation of livestock movements (with reduced labour inputs), better pasture and fodder crop allocations to maximize the utilization of the feed-base, small herd management, animal health monitoring, and NRM
Additional applications specific to northern beef: performing clean musters and managing bull movements for joining
Additional applications specific to southern beef: managing pugging and applying strip grazing

					Next steps if producers proceed with investing in VHT through trial-buy option, full purchase, or co-investment scheme		
Adoption Stage	1 Target – beef industry to specify	2 Awareness and interest raising	3 Entry point	4 Developing and proving the value proposition	5 Installation	6 Application & integration	7 Adaptation & best practices
Early 2021-2023	• Producers with a close interest in VHT/open to adopt early	• Commercial marketing • Scientific publications • VHT project industry information • Word of mouth/social media	• Reseller, referral or online services • Early Adoption Program through commercial developer	• Set up demonstration properties to virtually/physically show generic & specific applications for northern/southern beef systems • Customisation of cost-benefit analysis with trusted agricultural consultants • Seek research funding for VHT beef cattle experiments	• Technical support by reseller, referral or online services • Producer training on how to use software and train animals – this could include a role for animal behaviour scientists to work with producers in understanding livestock responses to VHT	• Reseller, referral or online services to provide ongoing troubleshooting and advice on feasible applications • Integration of digital farm systems via Agtech consultants & VHT developer	• Experimentation with VH system to adapt to property conditions and desired uses • Building knowledge on how to use VHT for consistent outcomes & benefits
Established 2023-2025	• Producers who need to establish and align their interests with VHT	• All media channels	• Reseller, referral or online services • Establish an online VHT Communities of Practice (CoP) via local producer networks e.g. FutureBeef (north) BetterBeef (south) or State Ag Department	• Proven value proposition for certain applications for the northern/southern beef industry • Customisation of cost-benefit analysis with certified VHT agricultural consultant • Conduct further beef cattle experiments	• Technical support by reseller, referral or online services • Commercial developer to provide certified training to beef & Agtech consultants in VHT installation and application procedures	• Continued commercial provision of trouble-shooting services • VHT CoP to share experiences with applying VHT • Industry bodies coordinate the integration of digital systems for the beef industry	• Trained beef & Agtech consultants to support VHT adaptation • VHT CoP to consolidate ways to adapt VHT to a variety of beef production systems
Mature 2025+	• Producers who need a matured value proposition	• All media channels	• Reseller, referral or online services to offer VHT as an "adoption package" for beef • Invitation to join formed online VHT CoP	• Visiting a suite of demonstration properties to represent beef system diversity • Developed method for producers to self-evaluate cost:benefit that takes into account specific production features • Finalise findings from VHT animal experiments	• Technical support by trained and certified beef consultants/trusted advisers in VHT installation/application	• Trained agtech consults to provide VHT trouble-shooting services • VHT CoP consolidate experiential proof of applications • Seamless integration of VHT with other digital systems for beef	• VHT CoP to work with industry bodies to develop VHT Best Practices for beef to achieve 'triple-bottom-line" • Development of VHT Big Data analytics as a knowledge input to decision making

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3. Suggested adoption pathway - Dairy Industry: prepare for adoption within the next 3 years

VISION: To provide dairy producers with enough evidence and support for making an informed decision about adopting virtual herding technology for their farming system.

Enabling VHT adoption at a policy level
State regulations: change current regulations to permit commercial use in Victoria, NSW, ACT, South Australia, Western Australia and Northern Territory
Public education campaigns: to manage public perceptions and minimize misconceptions about VHT
National protocols: for ownership, access and use of on farm Big Data to ensure clear benefits for producers
Industry strategy: to accelerate the adoption of technology that provides production insights and enables better decision-making on farm (DA Strategic Plan 2020-2025)

VHT adoption at the farm level (see Appendix 3 for more details about anticipated applications for VHT)
General applications: automation of livestock movements (with reduced labour inputs), better pasture and fodder crop allocations to maximize the utilization of the feed-base, small herd management, animal health monitoring, and NRM
Additional applications specific to dairy: precision management of feed and nutrition and easier operation of turnout blocks.

Adoption Stage	1 Target – dairy industry to specify	2 Awareness and interest raising	3 Entry point	4 Developing and proving the value proposition	*Next steps if producers proceed with investing in VHT through trial-buy option, full purchase, or co-investment scheme* 5 Installation	6 Application & integration	7 Adaptation & best practices
Early 2022-2024	• Producers with a close interest in VHT/open to adopt early	• Commercial marketing • Scientific publications • VHT project industry information • Word of mouth/ social media	• Reseller, referral or online services • Adapt Early Adoption Program designed for dairy industry based on the industry's needs/anticipated applications	• Set up demonstration properties to virtually/physically show generic & specific applications in the 8 dairy regions • Customisation of cost-benefit analysis with trusted agricultural consultant • Seek research funding for VHT dairy cattle experiments	• Technical support by reseller referral or online services • Producer training on how to use software and train animals – this could include a role for animal behaviour scientists to work with producers in understanding livestock responses to VHT	• Reseller, referral or online service to provide ongoing troubleshooting and advice on feasible applications • Integration of digital farm systems via agtech consultants & VHT developer	• Experimentation with VH system to adapt to property conditions and desired uses • Building knowledge on how to use VHT for consistent outcomes & benefits
Established 2024-2027	• Producers who need to establish and align their interests with VHT	• All media channels	• Reseller, referral or online services • Establish an online Community of VHT Practice via DA's Research Development Programs or State Ag Department	• Proven value proposition for certain applications for the dairy industry • Customisation of cost-benefit analysis with certified VHT agricultural consultants • Conduct further VHT dairy cattle experiments	• Technical support by reseller, referral or online services • Commercial developer to provide certified training to dairy & agtech consultants in VHT installation and application procedures	• Continued commercial provision of trouble-shooting services • VHT CoP to share experiences with applying VHT • Industry bodies coordinate the integration of digital systems for the dairy industry	• Trained dairy & agtech consultants to support VHT adaptation • VHT CoP to consolidate ways to adapt VHT to a variety of dairy production systems
Mature 2027+	• Producers who need a matured value proposition	• All media channels	• Reseller, referral or online services to offer VHT as an "adoption package" for dairy • Invitation to join formed online VHT CoP	• Visiting a suite of demonstration properties to represent dairy system diversity • Developed method for producers to self-evaluate cost:benefit that takes into account specific production features • Finalise VHT animal experiments	• Technical support by trained and certified dairy consultants/trusted advisers in VHT installation/application	• Trained agtech consults to provide VHT trouble-shooting services • VHT CoP consolidate experiential proof of applications • Seamless integration of VHT with other digital systems for dairy	• VHT CoP to work with industry bodies or Focus Farm Program to develop VHT Best Practices for dairy to achieve 'triple-bottom-line" • Development of VHT Big Data analytics as a knowledge input to decision making

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4. Suggested adoption pathway – sheep/mixed production: maintain interest over the decade

VISION: To provide sheep/cropping producers with enough evidence and support for making an informed decision about adopting virtual herding technology for their farming system.

Enabling VHT adoption at a policy level
State regulations in Victoria, NSW, South Australia, Western Australia and Northern Territory to permit commercial use
ublic education campaigns to manage public perceptions and minimize misconceptions about VHT
ational protocols for ownership, access and use of on farm Big Data to ensure clear benefits for producers
ndustry strategy context - to improve the uptake of new technologies in the red meat industry (MLA strategy 2025) to develop and deliver technology and systems that improve productivity through R&D and adoption (AWI National Wool Research, Development and Extension Strategy 2018-2022)

VHT adoption at the farm level (see Appendix 3 for more details about anticipated applications for VHT)
eneral applications automate livestock movements, better pasture and fodder crop allocations to maximize the utilization of the feed-base, small herd management, animal health monitoring, NRM
Anticipated applications specific to sheep/mixed farming: grazing crops without physical fences and creating smaller mobs during lambing season for easier monitoring to improve lamb mortality rates.

At present there is no commercial product available that is specifically designed for sheep. The current neckband is not easily adapted therefore another approach is needed together with significant investment in R&D to design and trial a suitable VHT prototype. It is important to keep the sheep industry engaged with virtual herding technology to maintain general interest in precision livestock management and the other benefits that can come from implementing digitalized, automated livestock systems.

Adoption Stage	1 Target – whole industry	2 General Awareness and interest raising
Maintain General Interest	Sheep/mixed production	• Commercial marketing • Scientific publications • VHT project industry information • Word of mouth/social media

Adoption stage	3 R&D process			4 Begin Adoption Pathway
Research & Development 2025+	• Commercial developer to seek venture capital/public funding to create a suitable VHT prototype for sheep	• Co-design the research program with sheep/cropping producers to capture the applications and value they anticipate from adopting VHT	• Commercial developer to partner with universities and RDCs for research funding to trial a VHT prototype designed for sheep	• Adoption pathway to continue similar to beef and dairy once there is a commercial release of a VHT product suitable for sheep livestock.

5. Final recommendations

The final recommendations provide clear direction to government, industry, scientific community, VHT commercial developers, agricultural advisory sector, livestock value chain actors and producers for how to support VHT adoption through strong leadership, cross-industry collaborations and working at multiple levels (policy, program, on-ground services and participation). The successful implementation of VHT on-farm will be enhanced by a Community of Practice (CoP) approach. Further details on the establishment of CoP groups are provided at the end of this Technote.

FEDERAL AND STATE GOVERNMENT

1. Recognise VHT as a mechanism for implementing effective grazing practices
2. Adoption may be funded under regional Natural Resource Management (NRM) schemes, Landcare Australia or Caring for Country when used for achieving environmental outcomes (public goods).
3. Incorporate VHT into current "honest-brokering" roles that independently assess new agricultural technologies for adoption by agricultural industries.
4. State governments to continue liaising with commercial developers, research institutes, industry bodies and animal welfare organisations to review state regulations controlling the commercial use of VHT.
5. State governments to oversee monitoring programs for animal welfare compliance across industries.
6. Co-establish VHT Communities of Practice (See Recommendation 21 for more details).

INDUSTRY BODIES (RESEARCH DEVELOPMENT CORPORATIONS AND FARMER BASED ORGANISATIONS)

7. Coordinate industry responses to emerging adoption challenges and risks e.g. Co-establish VHT Communities of Practice (See Recommendation 21 for details) and develop a VHT education campaign to proactively inform the public about this technology for all livestock industries.
8. RDCs to work with regional NRM bodies and/or food retailers to monitor the usage of VHT in compliance with any NRM Landholder Agreements and Farm Assurance Programs.
9. RDCs to consider leading the development of industry guidelines or Best Management Practices for using VHT responsibly and ethically to minimize socio-ethical risks.
10. Farmer Based Organisations (FBOs) to 'seed' this technology into mainstream farming systems targeting certain proven applications, which would help to build trust in the functionality of this technology.

SCIENTIFIC COMMUNITY

11. Seek funding (RDCs, Federal or State Government) for continued research on the long-term impacts on animal welfare and productivity outcomes from applying VHT in beef, dairy and sheep industries.

COMMERCIAL DEVELOPER

12. Lead the development of the VHT knowledge system through accessible and updated information.
13. Consider building and expanding VHT technical and advisory services in the agricultural advisory sector by offering in-house training or certified training programs.
14. Consider co-investing with RDCs or FBOs in setting up a suite of VHT Demonstration Farms across Australia's production regions in beef, dairy and sheep.

AGRICULTURAL ADVISORY SECTOR

15. Continue building skills and knowledge in integrating and applying digital agricultural systems in the livestock industries, including VHT with the support of RDCs, FBOs and the commercial developer to acknowledge that agricultural advisers do not have abundant time or money for professional development.
16. If possible, establish systems for monitoring and evaluating the adoption experiences of their producer clients and share any insights for cross-industry learning in partnership with the relevant RDC.
17. Co-establish VHT Communities of Practice (See Recommendation 21 for more details).

LIVESTOCK VALUE CHAIN (PROCESSORS, FOOD RETAILERS/DISTRIBUTORS)

18. Work with producers, industry bodies and independent auditors to explore the possibilities for novel markets and branding opportunities from managing and tracking livestock responsibly and transparently using VHT.

LIVESTOCK PRODUCERS

19. Co-establish VHT Communities of Practice (See Recommendation 21 for details).
20. Consider hosting a VHT demonstration farm/property or participate in a VHT Focus Farm program.

VHT COMMUNITY OF PRACTICE

21. Possible process for establishing VHT Communities of Practice: functions at an industry and cross-industry level.

Establish a shared interest group in VHT → Identify CoP Chair/Network Broker, participants & charter → Develop shared practices for knowledge sharing, problem solving, trials etc. → Communicate lessons learned & document emerging issues → Continue supporting VHT adoption pre-post sales

Who could initiate it:

- (formal) State government departments providing agricultural extension services who may embed a VHT CoP within a relevant project or RDC extension officer to embed in an RDC funded program
- (informal) Agtech consultant in production region or livestock producer as an opinion influencer

How it could be resourced:

- public or industry funding
- completely self-directed and voluntary - any customized one-on-one VHT advice to be paid for by producer

Who could manage it:

- CoP Chair/Network Broker- self-selected or nominated producer, agtech consultant, sector researcher, advisor, RDC or state department extension provider to manage the communications, development of a CoP charter, point of contact, administer activities
- CoP Leader to run activities – leader may change according to the topic, task & skills required,

How it could operate:

- Using an online platform (e.g. Facebook Groups, AgriFutures CoPs hosted by Extensionaus or Learning Management System like Moodle)
- Invite CoP participants through an Expression of Interest process
- Some examples of CoP outputs: technical articles, farmer case studies, videos, webinars, connections to blogs, dedicated newsletter, Q&A Help Forum and international expert panels to learn about implementing virtual herding technologies in other national contexts (e.g. producers, developers, researchers and advisers from New Zealand, Norway, United States of America, Scotland)
- VHT CoPs to hold cross-industry webinars or workshops to enable learning across beef, dairy and sheep industries based on common issues and opportunities in livestock production.

How could it be rolled out:

- Establish a VHT CoP for each industry (beef, dairy and sheep/mixed production) as a pilot by state government department or RDC – if successful make arrangements for continued resourcing of VHT CoPs (e.g. compensation for time given by CoP Chair/Network Broker, IT and administration support) for each industry based on shared interests, with scope to develop VHT CoPs at a production-region level if there is a call for more place-based learning and support
- Establish a register for informal CoPs that emerge
- Given the timeline for VHT adoption, CoPs for the beef industry are likely to be piloted and established first

Useful resources:

AgriFutures (2018) Automated Milking Systems (CoP) – Milking Edge, accessed at >
https://extensionaus.com.au/automaticmilkingsystems/home

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https://www.msfhr.org/sites/default/files/Community_of_practice_guide.pdf

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APPENDIX 1 – VHT STAKEHOLDERS AND KEY VHT ADOPTION CONSIDERATIONS

PARTICIPATORY TECHNOLOGY ASSESSMENT

Since 2017, we have been engaging a range of stakeholders with virtual herding technology Participatory Technology Assessment. Our approach to understanding the adoption and integration issues with virtual herding technology is based on a Participatory Technology Assessment (PTA) process that is commonly used in Europe for assessing new scientific and technological developments. PTA in our project is about inviting a range of stakeholders across the livestock value chain who may have an interest in or be impacted by virtual herding technology for the purpose of deliberating on the opportunities, risks, and challenges with this technology. We used focus groups and semi-structured interviews as our preferred methods because this technology is in a pre-commercial stage of development and stakeholders do not have direct experience with the technology. Our methods provided an opportunity to familiarise people with VHT and gain an in-depth understanding of what people think about this technology through a group conversation and individual responses to a question sheet.

LIVESTOCK VALUE CHAIN		
Stakeholder type	**No.**	**Method**
Beef, dairy and sheep producers from Victoria and Queensland.	31	4 Focus Groups (2017)
Agricultural advisers from the public and private sector	14	1 Focus Group (2018)
Natural resource managers from catchment management organisations	15	2 Focus Groups (2018)
State Government agriculture and environmental departments from Victoria and Queensland	4	2 Semi-structured interviews (2018)
Food processing company staff (dairy) (Currently recruiting a red meat processor)	1	1 Semi-structured interview (2019)
Food retail companies	2	2 Semi-structured interviews (2019)
TOTAL	**67**	

KEY CONSIDERATIONS FOR VHT ADOPTION ACCORDING TO OUR STAKEHOLDERS

We have distilled our findings as six key considerations for adopting and implementing virtual herding technology from our Participatory Technical Assessment and Cost Benefit Analysis (see Appendix [2] for more details about our research methods). These considerations are based on engaging with beef, dairy and sheep producers, agricultural advisers, regional natural resource managers, state government department personnel and food companies (retailers and a processor).

We asked them all to consider what they think are the benefits, opportunities, risks and challenges for adopting and implementing VHT on livestock farms and what implications there might be for their sector from VHT adoption. The Key Considerations (KCs) are grouped as follows:

Primary Considerations on-farm – the value proposition and support

1. Understanding the anticipated applications of VHT
2. Transforming the Proof of Concept into a ‘strong’ value proposition
3. Developing a ‘fit-for-purpose’ VHT support system

Secondary Considerations beyond-the-farm – the enabling environment for adoption through policy

4. Defining equitable and transparent data governance

5. Maintaining the social license of livestock producers
6. Regulating the use of VHT

KEY CONSIDERATION 1: UNDERSTANDING THE ANTICIPATED APPLICATIONS OF VHT

Most producers and other stakeholders anticipated that VHT will generate multiple benefits as a flexible and moving fence that offers a non-stop animal monitoring system that could be used on both private and public lands. When given the opportunity to imagine what VHT could do for livestock production, the applications anticipated were wide-ranging including common responses such as:

- better pasture and fodder crop allocations to maximize the utilisation of feed-base
- micro-management of a sub-herd or individual animals
- reduction in labour costs
- effectively managing different land classes of the property for environmental outcomes and improved pasture management
- being able to manage and monitor livestock remotely (on or off farm)

More uncommon responses included using VHT for bushfire management (reducing fuel loads with strategic grazing), linking VHT with regional food policies as a way of promoting economically viable local produce, keeping livestock safe from hazards such as steep banks or dams that are drying out, developing new understandings of animal behaviour by observing animal responses to VH technology and potentially breeding out those animals who do not respond appropriately to the cues and imagining that VHT could be used as a warning system for unfavourable weather conditions or wild dog presence to trigger the movement of livestock to safer areas.

There could be value in defining VHT adoption pathways per industry based on supporting specific applications and anticipated benefits that are deemed relevant to each livestock industry. Livestock producers responded to our focus group questions with their own farm in mind, and/or a generic livestock farm and/or their industry in general. Table [3] is a comprehensive list of industry specific applications and benefits mentioned during the focus groups with livestock producers.

Table 1: Industry specific applications and benefits anticipated from adopting VHT

Northern Beef	• better management of bull movements (moving them in and out of the main herd) • controlled joining of bulls and heifers • Heifers that are VH trained could be a selling point • Herd class segregation • Roll-call of livestock i.e. real-time mapping of livestock locations, which can assist with achieving “clean” musters
Southern Beef	• manage pugging in paddocks during the wet months • Better control of livestock could assist with targeting specific meat markets • Manage sensitive areas of land appropriately e.g. failed cropping area • used in high rainfall beef production for strip grazing
Dairy	• more finely tuned approach to nutritional management and efficient use of supplementary feeding for individual animals and large milking herds • reduced feet soreness by use of flexible laneways • improved management of livestock on a turnout block • having VHT integrated with standard dairy industry technologies and programs as a ‘packaged’ offer • Avoids having to expose farmers/farming staff to the risky practice of physical fencing in steep, hilly country
Sheep + cropping/beef	• better management of ram movements (moving them in and out of the main herd) • informing sheep genetics (Australian Sheep Breeding Values) • monitoring ewes during lambing season • Creating smaller mobs during lambing season for easier monitoring • combine with industry programs e.g. Lifetime Ewe Management • aggregating VH farm data to generate industry goods e.g. biosecurity management

(see Appendix [4] for a full list of potential applications and benefits identified by producers)

KC1: The adoption process should include a sensitivity towards managing the expectations of potential VHT adopters to ensure that there is a realistic understanding of the current capabilities of the technology as well as offering an industry specific focus

KEY CONSIDERATION 2: TRANSFORMING THE PROOF OF CONCEPT INTO A 'STRONG' VALUE PROPOSITION

The value proposition for adopting VHT becomes more ambiguous when we take into consideration the mix of perceived uncertainties and potential risks expressed by our VHT stakeholders about the eShepherd® product. Areas of concern cover cost-benefit, technology functionality and animal welfare.

The responses in Table [4] represent a sample of the risks, uncertainties and challenges with adopting and implementing VHT on livestock properties. It should be noted that these perceived uncertainties and risks are not necessarily accurate or have high probability e.g. defective battery life of neckband, because some of these perceived risks can be mitigated through accurate information, observation of technology and training using the technology; at the same time some uncertainties and risks are accurate with high probability e.g. variable and sometime low level regional connectivity in Australia.

Table 2: Stakeholder perceptions of the uncertainties and risks with adopting and implementing VHT

Uncertainties	Potential risks
Return on Investment • uncertainty of ROI for small scale farming, established automated systems or simple applications of VHT – i.e. adding value from investment may require a complex application(s) **Farm system integration** • Uncertainties and challenges with how to integrate with other digital farming technologies/systems **Reliability** • Doubts about the capacity of the battery to provide reliable power over time and in cloudy conditions (through solar power trickle) • Uncertainty that VHT can reliably deliver the desired multifunctionality **Technology performance in variable conditions** • Uncertainty it can function during power outages • Hilly country or gullies may limit the efficacy of VHT	**Animal health and wellbeing** • Neckband could cause choking in young and growing livestock or snag on infrastructure/vegetation • Neckband rubbing off hair and skin around animal's neck leading to wounds or ulcerations **Connectivity** • Functionality and performance of technology could be compromised by poor Internet/mobile connectivity resulting in 'escaped' livestock **Obsolescence** • VH technology could be superseded by a 'new' technology in a short period of time **Durability** • Risk of losing or damaging collars through wear and tear, adding a replacement cost

(see Appendix [5] for a full list of anticipated challenges and risks identified by producers)

In terms of the cost-benefit for adopting virtual herding technology as a determinant of adoption, the following draft results are from the three case farms in Victoria (dairy and sheep) and Queensland (extensive beef). These key findings may assist with overcoming the uncertainties producers had with the ROI from adoption virtual herding technology. The price of VHT has yet to be established, so the approach taken in this study was to calculate the break-even cost per animal that the farm business could pay for the technology based on the anticipated benefits.

Dairy: The benefits assumed for each application and the break-even cost of the technology is summarised in Table [5]. These results indicate that if the VHT is only used to fetch cows then the maximum the farmer could pay is $77 per cow. However, if labour savings and production benefits are combined (e.g. increased milk production), then the investment could be more than $300/cow.

Table 3: Applications of VHT on a pasture-based dairy, the anticipated benefits and break-even cost ($/cow) that a farmer could pay to achieve a 15% return on investment over a 10 year period.

Application of VHT	Benefit	Break-even cost
1. Fetching cows for milking to save labour and ATV use	• Labour savings of 1 hour/day for 330 days per year. • Vehicle fuel, repairs and maintenance savings of $3,000/year	$77/cow
2. Splitting pasture allocation to enable later milked cows to have access to a greater quantity and higher quality of pasture	One third of cows in the herd has: • Milk production increase 0.075 kg milk solids/cow/day [A] • Improved reproduction to extend the life of cows from 4 to 5 lactations.	$238/cow
3. Applications 1 and 2 combined	• As above.	$319/cow
4. Flexible grazing in wet conditions to avoid pugging and pasture damage	• 1.5 t DM/ha of pasture saved on 30% of the milking area every second year.	$77/cow

[A] ithout compromising the production of earlier milked cows.

Mixed sheep-beef: The benefits and break-even cost of the technology is summarised in Table [6]. Investment in VHT on out blocks to manage beef cattle appeared to be worthwhile, but it does not appear to be for sheep even when multiple benefits are combined.

Table 4: Applications of VHT on a mixed sheep-beef farm in western Victoria, the anticipated benefits and break even cost ($/head) that a farmer could pay to achieve a 15% return on investment over a 10 year period.

Application	Benefit	Break-even cost
1. Use on beef herd on the two outblocks that are distant to the home farm to save labour and control grazing management	• Reduced labour by 1.5 days per week on each block. • Increased pasture utilisation by 10%.	$400/cow
2. Use on sheep to improve pasture utilisation and persistence on home farm by grazing on the hills and gullies.	• More silage conserved (0.3 t DM/ha) and less hay purchased. • 50 ha less of pasture resown per year	$47/head sheep
3. Application 2 plus manage riparian zones without spending more on permanent fencing.	• Capital expenditure on 30 km fencing avoided.	$66/head sheep
4. Application 3 plus increasing lamb survival by running smaller mobs at lambing.	• Increased survival rate of twin lambs from 140% to 170% by reducing paddock size from 15 ha to 4 ha.	$83/head sheep

Extensive beef: The benefits and break-even cost of the technology is summarised in Table [7]. The use on bulls only has a high break-even cost, but it is reliant on the neckbands being applicable to the bulls. For applications on the whole herd, increased carrying capacity achieved through better control of grazing management had a realistic breakeven cost

Table 5: Applications of VHT on an extensive beef production system in western Queensland, the anticipated benefits and break even cost ($/head) that a farmer could pay to achieve a 15% return on investment over a 10 year period.

Application	Benefit	Break-even cost
1. Use of VHT on bulls only to remove them from the breeding herd[A].	• Avoid a muster with labour, helicopter hire, fuel savings of $2000 per year	$588/bull
2. Partial mustering of herd for Branding and Weaning	• Labour, helicopter hire, fuel savings of $1000 per muster, or $2000 per year.	$33/cow
3. Improved carrying capacity from greater control of grazing management	• Increase herd size by of 20% (50 cows	$254/cow
4. Increased weaning percentage supported by grazing higher quality pastures	• Additional weaners (up to 5%)	To be determined
5. Improved liveweight gain	• Weaning liveweight increased by 10 kg	$102/cow

[A] Assumes that VHT is suitable for use on bulls.

In summary to the Cost Benefit Analysis, the dairy and beef case studies, labour savings alone were not enough to achieve break-even costs in a realistic range. Pasture or livestock production gains were essential to achieving realistic break-even costs. The break-even cost is very sensitive to the level of production increases achieved and lifespan of the technology.

VHT in sheep production systems does not appear to be profitable because of the large number of neckbands required. However, if the same benefits could be achieved by having neckbands on approximately half of the ewes then the technology may be profitable. The case study farmers identified that having other functions integrated with VHT, such as heat detection and animal health monitoring, would increase the likelihood of adoption.

KC2: The cost-benefit results suggest that a return on investment will be reliant on the technology being applied as a multi-purpose innovation that provides flexibility and precision.

KEY CONSIDERATION 3: DEVELOPING A 'FIT-FOR-PURPOSE' VHT SUPPORT SYSTEM

It is clear across all VHT stakeholders that is it is critical to develop and provide appropriate and comprehensive support to those considering adopting virtual herding technology. This became apparent through direct comments, discussion points and the types of questions asked to the commercial developer during the open Q&A session as part of the focus groups.

The critical need for a 'fit for purpose' VHT support system was demonstrated through:

- Identifying what new knowledge and skills are needed for VHT adoption:
  - understanding the animal welfare aspects, which should be part of any training
  - understanding how the audio cues and electric pulses are triggered and sequenced
  - managing the waterpoints in virtual paddocks i.e. making sure there is access to water in an area that may not be located near set water points
  - managing, interpreting, and applying the data outputs generated by VH
  - installing, animal training and maintenance of system

- the volume of suggestions for adoption and extension activities:
  - demonstration farms showcasing VHT applications in different farming contexts
  - engaging farmers in VHT trials
  - YouTube videos to explain use of VH system
  - Online training courses
  - Standard Q&A webpages /step-by-step guide
  - Training teams of local trouble-shooters and farm advisers – on hand skilled people to respond to technical and application issues as they arise (tertiary level graduates, precision agriculture specialists, Meridian, stock agents, fencing contractors, stock agents, software developers, experienced farmers, ICT local businesses)

- A perception that a lack of comprehensive VHT training and ongoing support could pose a risk to VHT adoption because it could lead to the (unintentional) misuse of the technology causing animal welfare issues or animal harm, for example through controlled starvation of livestock from inappropriate virtual paddock dimensions and locations

It can be inferred from these findings that the technology itself does not lead to negative outcomes, rather it is the VHT user (adopter) and their knowledge, competency and practices that is the determining factor which is partially determined by the level and quality of support that exists.

Developing a system of support for VHT adoption and implementation is not solely a skills gap challenge for the farming community but also one of identifying and enrolling a diversity of new and non-agricultural players into the agricultural innovation and adoption process. Nolet and Mao (2018) accentuate that need for entrepreneurs in agricultural technology to network and collaborate with industry advisors and consultants to benefit from their agricultural networks for collective problem solving, market segmentation and access to producers for farm trials. Industry advisors and selected producers may also take up the roles of "intermediary", "translator" or "technology champion" to ensure interactions between developers, producers and the wider innovation community are appropriate and worthwhile for all involved (Nolet and Mao, 2018).

This sentiment of involving a range of expertise and professions in the agtech innovation space to support both the innovation process and adoption is reflected in the range of support services that were self-identified by the VHT stakeholders who are either part of the livestock value chain, regional natural resource management sector or state government department. Table [8] showcases the services described by VHT stakeholders with a designated adoption support role to represent their service. (See Appendix [6] for a table which shows which stakeholder self-identified what support service and the incentive to be involved)

Table 6: Adoption support roles self-identified by VHT stakeholders.

Adoption support role	Service
Coordinator	coordinate and conduct on-farm trials and field days
Funder/subsidiser	provide grants/subsidies to livestock producers as a co-investment in VHT, if used for NRM outcomes
Promoter	promote VH technology as one of numerous innovations in the digital agriculture space promote the production efficiencies that could result from implementation to pasture-based suppliers
Assessor/ Honest Broker	providing a "neutral" or independent review of VHT
Referral	Refer potential livestock producers to the commercial developer/distributor
"Socialiser"	Introduce and normalise VHT across livestock producers in production regions
Extension provider	developing a customised value proposition for each client; once adopted, assisting livestock producers with identifying the key applications to generate the most value communicating/responding to questions about the technology from supplier base
Social network developer	creating a Community of Practice in applying VH technology for collective problem-solving to encourage adoption and use
Project participant	map potential VHT benefits to support the livestock industry and value chain
Distributor/retailer	be a point of sale and distribution of VH products
Product developer	Developing new food and fibre product lines and markets that promote the environmental and animal welfare credentials of agricultural products produced using VHT
Connector	linking VHT to the food value chain
Integrator	capacity to resource collaborative projects that aim to integrate digital technologies and analytics into a seamless online platform

KC3: VHT adoption pathway(s) should consider a range of support roles, services and actors to be involved to extend the reach and effectiveness of the adoption process

KEY CONSIDERATION 4: DEFINING EQUITABLE AND TRANSPARENT DATA GOVERNANCE

The issue of equitable and transparent data governance in relation to big data generated by the eShepherd® system was not always spontaneously brought up during the focus group discussions. However, when the topic was prompted or unprompted, there was a general concern and uncertainty across most of the VHT stakeholders about how the farm-based data would be governed in terms of:

- data management
- data ownership
- data security
- data privacy
- data accessibility
- data sharing
- data integration

The sheep focus group emphasised that producers should have control of their own VH data and report outputs. On the other hand, this same group could see the value in aggregating VH data across a region or industry to benefit the whole industry e.g. predicting meat and wool yields or biosecurity management.

> *Intelligent processing and analytics – for Big Data this is also more challenging because of the large amount of often unstructured, heterogeneous data which requires a smart interplay between skilled data scientists and domain experts.* (Wolfert et al., 2016:79)

VH stakeholder discussions about governance of big data can be linked to broader and ongoing discussions at the national level regarding Australia's progression towards digital agriculture. Meat and Livestock Australia has set out a vision for the governance of livestock big data as part of a strategy for developing digital livestock value chains. Meat and Livestock Australia would like to see:

- all farms connected to the internet
- industry databases connected in an open platform (enabled by open access data standards)
- improvements in industry data interoperability (industry agreement on data supply and access standards)
- better use of industry information (develop and implement of an industry data assurance plan)

This vision could be used as a reference point when defining an enabling environment for the adoption of VHT.

KEY CONSIDERATION 5: MAINTAINING THE SOCIAL LICENSE OF LIVESTOCK PRODUCERS

> KC4: VHT adoption could be encouraged through strategies to achieve equitable and transparent governance of Big Data generated by the virtual herding digital system.

All VHT stakeholders brought up and engaged with the issue of maintaining the social license of livestock producers. However, there were subtle differences in the 'angle' of concern. The different angles of concern were:

- imagining that the general public will be concerned with the use of an electric pulse to manage farm animal behaviours or the confinement of livestock to smaller virtual paddocks than the traditional open pasture – leading to society assessing the technology as 'unethical'
- suggesting that VHT adoption could be constrained by an inability to control public messaging about VHT through social media, resulting in popularised misinformation and mythmaking about the technology, potentially triggering animal activism on livestock properties
- linking these concerns with the impact it could have on livestock industries and markets in general if VHT is viewed by the public (and animal welfare organisations) as 'unethical'
- perceiving the Australian public as having limited knowledge of agriculture and animal production in general, let alone having a good understanding about electric fencing, electric dog collars and virtual herding technology - therefore it is inferred that that there is a significant knowledge-deficit to address

Most of the VHT stakeholders did not express their concerns for the use of audio cues and an electric pulse to manage animal behaviours – partially because they were provided with the technical details of the technology during the engagement sessions, which included an awareness of the animal welfare principles used to guide the design. It became apparent that VHT stakeholders recommend that 'someone' should be responsible for developing accurate, accessible and relatable public messaging about VHT– to inform, advocate and shape public perceptions of VHT.

Feedback from our VHT stakeholders indicates that any public messaging or educational campaigns about virtual herding technology should be detailed enough to address any public misconceptions or uncertainties and be proactive, rather than reactive. Any public messaging should emphasize the following details as suggested content:

- the neckband does not continually delivery an electric pulse to animals when the animal is close to the virtual fence or in the exclusion zone, rather the electric pulse will only be emitted under certain conditions (e.g. after two audio signals, if the animal is moving towards the exclusion zone within 5 meters of the virtual fence)
- no electric pulse will be delivered if the animal is distressed, moving towards the inclusion zone, is standing still or resting

- Animal training is involved
- Robust measures of animal welfare during the project's animal trials showed no increase in physiological stress levels of research animals nor did they display any distressing behaviours
- animal health and wellbeing can be monitored using VHT for improved animal welfare

The project team has been working with selected animal welfare organisations in Australia as a 'proxy' for working directly with the general public as these organisations are considered key influencers of public opinion. At present, the RSPCA is not supportive of the commercial use of virtual herding technology (any device that uses an electric pulse to control animal behaviour) in Australia's livestock industries. State and territory animal welfare legislation determines what devices can or cannot be used to manage livestock. Table [9] provides a summary of the current legal status of VHT in each state and territory.

Table 7: Current legal status of VHT per state and territory

States and Territories	Regulation
Queensland, New South Wales and Tasmania	Can be used for research and commercial purposes
Victoria, South Australia, Western Australia, Northern Territory and ACT	Can be used for research purposes only, under strict conditions

Public opinion on the ethics of agriculture is important to consider as the future of Australia's production industries will be increasingly driven by the needs and preferences of consumers and the community. The community's social and regulatory power determines what production is allowable. According to the Rural Industry R&D Corporation, meeting the needs of consumers and communities will require greater connectivity and flow of information up and down food and fibre value chains (RIRDC, 2018:10).

KC5: The ethical and regulatory status of VHT will be important to discuss as part of the adoption process for informed decision making.

KEY CONSIDERATION 6: REGULATING THE USE OF VHT

In terms of developing specific VHT policy or guidelines for natural resource management applications at the state or industry level, the findings from the 2018 workshops and engagement meetings indicate that there is no unanimous support for this idea.

- Victorian VH stakeholders tended to agree that a VH policy will be needed at some point to ensure VH technology is used consistently for NRM outcomes across the catchment regions if it becomes adopted widely.
- Queensland VH stakeholders tended to argue that that there are already enough regulations and mechanisms for managing the state's land and water resources therefore there is no need for a specific VH strategy to be developed – it was thought that too much regulation can act as a barrier to the adoption of innovative farm practices.

In terms of regulating the use of VHT in the context of value chains, both food companies engaged emphasized the importance of regulating the use of virtual herding technology on-farm to verify and protect the integrity of branded products labelled as animal welfare and/or environmentally friendly. According to the food companies engaged, regulating the use of VHT would need to involve a system of monitoring and independent third-party auditing of producer compliance against certain agricultural production standards (industry, public or company standards).

New systems of provenance and compliance enabled by VHT will need to align with national and industry certification policies and programs. The National Farmers' Federation advocates for greater resources to be dedicated to accredited quality assurance through independent auditing programs and harmonising animal welfare standards and guidelines across all states and territories. These things are important to get right because traceability and quality assurance are key strategies for increasing the value of Australia's agricultural production (National Farmers' Federation, 2018) – and VHT could be a contributor to this.

The importance placed on regulating the use of VHT by stakeholders further down the value chain, suggests that it will be important for the VHT adoption and implementation pathway to include scope for the development of a Best Management Practice (BMP) program. The Queensland Farmers' Federation (2019) has created a set of useful guiding principles for developing Best Management Practice Programs:

- government endorsed BMP programs to meet legal requirements, policy initiatives and community expectations
- continuous improvement of BMP through an adaptive management cycle
- tailored to suit different industries and regional needs
- support producers to achieve industry, market and societal recognition of their practices
- be broadly consistent with national and international certification programs
- utilize the best available science and R&D to underpin the BMP program

KC6 The development of Best Management Practices for VHT use ought to be a consideration for supporting industry-scale adoption for the purposes of regulating and integrating virtual herding production systems with livestock value chains, NRM regional strategies, government policy and community values.

APPENDIX 2 – VHT CONSULTATIVE PANEL (CP) AND RESPONSES TO THE DISCUSSION PAPER

VHT CONSULTATIVE PANEL MEMBERS

Alana Boulton | Meat & Livestock Australia |Northern Beef Adoption Project Manager
Andrew Morelli | Meat & Livestock Australia | Southern Beef and Sheep Adoption Project Manager
Aubrey Pellet | Chairman, Rural Financial Counselling Service Gippsland | dairy industry
Graeme Nicoll | DA Board Member | dairy farmer
Leandro Posteraro | Agersens | eShepherd Product Owner
Meera Cameron | Precision Agriculture | Research Officer
Nicolas Lyons | NSW Department of Primary Industries | Leader Dairy
Peter Small | Project Farmer Panel | sheep producer
Richard Rawnsley | Fonterra| Farm Source Paddock Specialist (Tasmania)
Rick Llewellyn | CSIRO| Group Leader, Integrated Agricultural Systems
Samantha Neumann | Livestock SA Board | Elders
Zac Economou | southern beef producer | agtech researcher

SECTION 1: KEY MESSAGES FROM CP RESPONSES

1) VHT is a complex technology and therefore requires significant adoption support

- Evidenced by a strong call for training and upskilling of producers and adoption support providers in the technical detail of VHT, integration of VHT with other precision farming systems used, trouble-shooting the system and the range of possible applications

2) The Generic Transfer of Technology model is not enough

- Evidenced by most CP members proposing a multi-approach or indicating that alternative approaches are needed
- When the Generic Transfer of Technology approach was selected, it was usually in combination with other approaches

3) Adoption pathway needs to be adaptive with a level of customisation built in

- Evidenced by comments made about the pathway needing to be "agile", "flexible" and "not rigid"
- Evidenced by a general theme that the adoption approach needs to involve a level of "farmer and market segmentation" to respond to diversity: in the development trajectory of each industry, biophysical features of a production region, producer needs and personal goals, evolution of VHT functionality and the current state of commodity markets etc.

4) Value proposition needs better defining and refining

- Evidenced by numerous comments made across the Panel's feedback that the value proposition for VHT needs to be clearer and made simple; it needs more detail about the costs involved and expected returns on investment; it needs to scope out the potential risks, it needs to manage producer expectations about what VHT can do for them including being obvious about the core functionality of the technology i.e. fenceless farming, and requires extension activities to demonstrate unambiguously the concept, the set up required, how to operate, possible applications, as well as what effective VHT practice looks like in a commercial context

5) Adoption pathway may need to be multi-staged

- Evidenced by some suggestions for the adoption process to begin with 1 application with a sub-herd and progress to multiple applications with the whole herd
- Evidenced by using certain adoption approaches when the applications are proven and carry minimal risk, while other approaches are needed when applications are 'unproven' and carry unknown risks

- Evidenced by some suggestions an adoption pathway starts with awareness/interest/evaluation campaigns that run at a regional scale/producer community scale, followed by the delivery of tailored adoption support services that run at the individual property scale

SECTION 2: OPTIONS FOR A VHT ADOPTION PATHWAY(S)

a) Approach/rationale

- No one definitive or 'popular' VHT adoption approach identified
- Most CP members proposed a combination of approaches or commented that there is no one adoption approach that will service the VHT audience therefore multiple approaches are needed
- Approximately half (at least 6 CP members) described an approach that explicitly involved a Community of Practice or collaborative partnerships

Table 8: Snapshot of the clustered approaches to VHT adoption with rationales

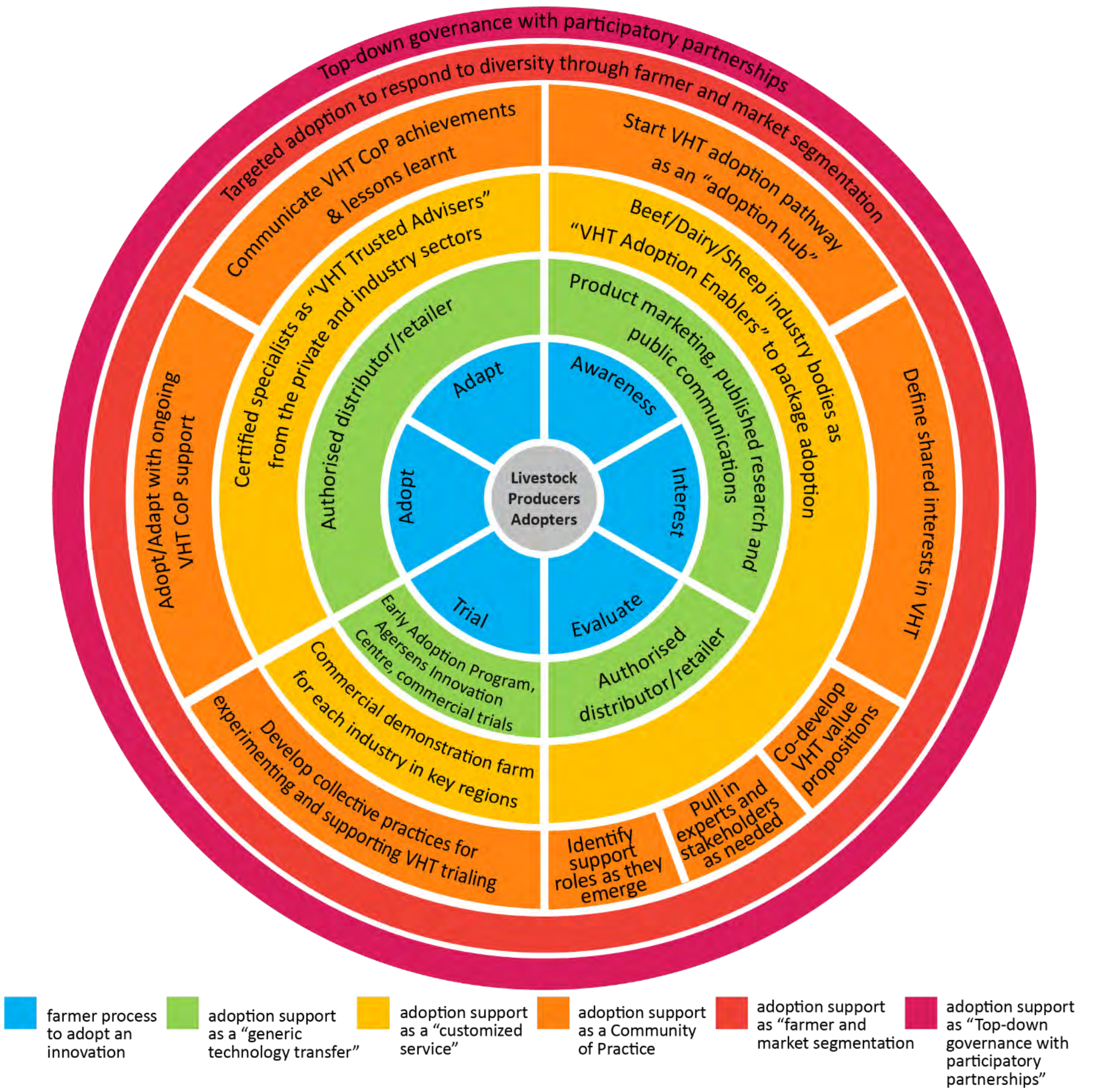
Cluster No.	Rationale
Adoption Pathway Cluster 1 (1 CP member) Option 1 "Generic Technology Transfer"	• The rate of adoption is less about the product or the ability of the product to provide a benefit, and much more dependent of the support to the client to get up and running – the After Sales care. • The team of people working with producers/adopters need to be well researched in the technology and they need to be able to provide a high-level of care and assistance with the implementation of the tech i.e. they need to be contactable, available on farm and able to quickly resolve issues. • While there is merit to leveraging an industry bodies backing to build a profile and boost the technology's exposure, the real gains in adoption has been continually witnessed through the step-by-step integration of the technology into the client's business.
Adoption Pathway Cluster 2 (2 CP members) Option 3 "Community of Practice"	• Due to the complex nature of VHT and the difficulty in getting producers to try new ag tech. • Need a progressive farmer-based CoP to build a critical mass of producers that can prove to the wider farming community the benefits from using VHT. • the complexities and multiple ways this technology can be adopted, requires a collaborative, systems thinking approach in order for it to be successful. • Different players of the value chain (on and off farm) could be potential users and benefit from the application of the technology, and would therefore have to work together and closer to the farmer to extract the value that appears can be generated.
Adoption Pathway Cluster 3 (2 CP members) Hybrid Options 1&2 "Generic Technology Transfer" with "Customized (industry focussed) Service"	• Industry Bodies involved would provide support for producers seeking to innovate not to advocate for a particular technology or product. • Commercial demonstrations would be financially supported by the product owner (Agersens) and seen as a training ground for Agersens, "trusted advisors" and retailer/distributor. • Trusted advisers would be commercial operators seeking to differentiate their services. • The diffusion model [represented by the Generic Technology Transfer option] and the customised adoption pathway would focus on using early adoption producers as well as engaging regional industry producer networks (e.g. Better Beef) to enable peer-to-peer demonstration and support and reducing the need for support from the commercial developer. • Support and education will be key to the longevity of VHT by field days, workshops, e-learning programs and using agricultural retail suppliers to help support and implement a VHT adoption program.
Adoption Pathway Cluster 4 (1 CP member) Combine Options 1&3 "Generic Technology Transfer" with "Community of Practice" - at sub-regional scale	• Acknowledge that Option 1 is a current model driven by livestock producers and technology provider, but places a significant amount of research and risk on the livestock producers, with limited opportunity to practically review the technology and little guarantee that the support from the distributor/retail network will be of high quality or ongoing. • Legislative requirements will make any continuity/consistency through national retailers extremely limited. • Community of Practice approach allows facilitation, collaboration and demonstration at a sub-regional level, potentially via well-established groups/methodologies in those sub-regions to respond to sub-regional specific challenges (collectively comparable constraints: connectivity, pests, landscape etc.). • While maintaining a commercial focus that is profit driven. • Livestock industry bodies lead adoption support, in circumstances is not the most efficient process and lacks commercial reality. • Demonstration farms are critical in increasing adoption, however specific packages/programs and appropriate accreditations can evolve naturally once customer (consumer/general citizen) requirements for the value chain are clearly understood.

Cluster No.	Rationale
Adoption Pathway Cluster 5 (1 CP member) Combine Options 2&3 “Customized (industry focussed) Service” with “Community of Practice”	• Industry leadership to launch and introduce the technology where there is emphasis on alignment and integration with other technologies and farming practices that would be industry specific in most cases. • Once there is a critical mass of VHT knowledge, a CoP approach is then viable and will be needed. • Community of Practice is best placed to organize non-direct consumers (supply chain stakeholders). • One of the most trusted recommendations often comes from other producers where producers can see and evaluate results in real world [and their own farm] comparisons. The demonstration farm model running as close to commercial as possible has merit. The best examples are collaborations backed by trusted experts and industry resources.
Adoption Pathway Cluster 6 (1 CP members) Multi-step process for Options 1,2 & 3 Generic Technology Transfer'', “Customized (industry focussed) Service” and “Community of Practice “Application driven CoP”	Step 1 • Option 1 is deployed when there is a high level of confidence, control, societal acceptance and proof that the desired outcome/s will be achieved. • Option 2 customised service used when the desired outcome has been identified and the assessment of the likelihood of success, implementation ease and risk has been assessed. Step 2 • Option 3 is used in situations where the VHT application is producer-driven need but is not well developed or where general social acceptance remains questionable. • VHT CoP key activities could include current situation analysis, determine the points of influence across the CoP, involve and partner. • VHT CoP should develop an agreed position assessment on the applications of VHT including uses that could generate benefits down the value chain, therefore a level of partnering with value chains is required.
Adoption Pathway Cluster 7 (4 CP members) Targeted adoption to respond to diversity “Farmer and market segmentation”	• different industries and different end users within industries see different applications for this technology therefore there will be different priorities, expectations and indicators of value, therefore different approach needed. • no one approach as it is dependent on where in Australia (sub-regional zones), biophysical features and the size of the property. • Farmer segmentation based on ABARES annual “Australian Agricultural and Grazing Industries Survey" to ensure adoption pathway statistically represents each VHT livestock industry. • The livestock industries (beef, dairy, sheep and others) are going through different evolutionary stages as well as fluctuating market situations (beef price, export, property market and others) and dynamic competitive forces within the grazier's alternatives (buying more land, genetic investment, adapting to export trends, etc) therefore the best model and pathway for VHT needs to be flexible, adaptive and agile.
Adoption Pathway Cluster 8 (1 CP member) “Top-down' governance with participatory partnerships” - as opposed to a common diffusion process	• The need for changes in state legislation. • Management of animal welfare aspects and related social license characteristics. • The requirement of a potentially certified, technical and advisory support networks. • Some opportunity for participatory processes once VHT has been established in commercial and large-scale enterprises.

A visual to represent the aggregation of approaches to support VHT adoption provided by the Consultative Panel.

Figure 1 could infer that multiple ‘layers of support’ are needed for the successful uptake of virtual herding technology in the Australian context.

Figure 1: Aggregation of the different approaches to VHT adoption



b) Goal/outcome of adoption pathway

- Goals: provision of a clear, simple value proposition; development of a flexible & responsive adoption pathway that adapts to a producer's situation, desired applications and network of people that will need to be involved
- Outcomes: Quantitative indicators of successful adoption e.g. regional benchmarking of production performance; VHT accreditation for certain applications to assist with entry into premium price markets and maintaining/improving the livestock industries track record in environmentally sustainable production

Table 9: List of goals and outcomes mentioned for each 'cluster'

Cluster No.	Goal/Outcome
Adoption Pathway Cluster 1 "Generic Technology Transfer"	• Develop a clear and robust business case for adoption. • Deliver a customised value proposition including a clear articulation of the benefits.
Adoption Pathway Cluster 2 "Community of Practice"	• Achieve good decision making and full utilisation of VHT by ensuring producers are aware of the benefits of VH, that the potential issues are addressed and that producers clearly understand the current capability/functionality of the VHT to manage their expectations of what it can do. • Successful adoption in terms of short learning curve and seeing benefits fairly quickly in terms of improved productivity and profitability.
Adoption Pathway Cluster 3 Hybrid of "Generic Technology Transfer" with "Customized (industry focussed) Service"	• First 50 VHT installations are a success. • If successful, then commercial adoption targets set with strong adaptive support targets locked in to allow the product usage to evolve. Possible adoption goals could be: • Improve and build producer capability around the product, benefits (productivity & Profitability), understand how the tech will increase time savings and animal welfare will not be compromised. • Help identify why the VHT is right for individual producers' businesses, by utilising producer demonstration sites – e.g. X number of producers in a region with X demo sites. • Regional benchmarking of animal performance or pasture productivity in producer groups like 'Better Beef'. • Verifiable/accreditation & revenue generating system for improving sustainable and environmental credentials to deliver premium products or branding. • End goal of VHT should have a clear value proposition for the producer to incentivise engagement and that VHT will deliver increased productivity and profitability.
Adoption Pathway Cluster 4 "Generic Technology Transfer" with "Community of Practice"	• Provide a clear pathway for adoption alongside a well-articulated value proposition. • Indicators of successful adoption in terms of NRM and animal welfare impacts on-farm rather than rates of technology adoption. • Develop Best VHT Practices to set KPIs for key applications.
Adoption Pathway Cluster 5 "Customized (industry focussed) Service" with "Community of Practice"	• All stakeholder expectations are met - e.g. ROI, quality of effectiveness, consumer awareness.
Adoption Pathway Cluster 6 Multi-step process for Options 1,2 & 3 - "application driven CoP"	• Start with the application and assess the productivity, profitability, sustainability and social benefits. • From this desired application/outcome, work back and determine the most effective adoption pathway, the adoption targets and the multiple actors required to achieve success on-farm/beyond the farm. • End result is an agreed adoption approach for each application. • if the required pathway is going to being informed by the outcome then the outcome needs be stated for e.g. by ? the adoption of the VH technology by ?% of ? producers in the region/s of ? will achieve?
Adoption Pathway Cluster 7 "Farmer and market segmentation"	• Present a technology that is fit for purpose product that suits the individual property without wasting producer money. • Build flexibility into the process (iterative) to respond to how successful the technology is on different properties. • Raise awareness of the technology and achieve a customised adoption process per farming enterprise to adapt the technology to the farmer's situation.

Cluster No.	Goal/Outcome
	• The task is to effectively communicate according to needs of the producer so they can realise the importance of the value in simple terms and in a simple manner e.g. saving time and money as well as better use of their resources to deliver more value per hectare is paramount. • Once that is achieved the adoption is relying on the communication pathways that are relevant to that particular market segment and usually have more traction when it comes from a familiar and trustful source. • Main goal is to increase awareness of VHT by top performing producers and demonstrate how the technology can be adapted to their enterprise. • Provide robust information, supported by data and case studies about the benefits of implementing this technology in real farm situations. • Troubleshooting and support to set up and use the technology as well as any integration with existing platforms/software. • Strategic advice for utilising the technology to assist producers with further integration and 'add-on' activities.
Adoption Pathway Cluster 8 'Top-down' governance with participatory partnerships"	• Effective risk management to manage the real or perceived animal welfare risk and/or threat to social license. • High short-term adoption targets are unlikely to be constructive until commercial use is better understood. • To help potential adopters understand the optimal price point, type of use(s) and system for investment.

c) Target audience

- Prime target for (non-CoP) VHT adoption approach is producers across the northern and southern cattle industries
- Prime target for CoP orientated adoption approach includes all livestock producers, advisers, researchers and other VHT stakeholders

Table 10: Key target audience for adoption approach for each 'cluster'

Cluster No.	Target audience							
	Top performing producers	**Early Adopters**	**Northern Beef**	**Southern Beef**	**Dairy**	**Sheep**	***All livestock producers**	**CoP audience**
Adoption Pathway Cluster 1 "Generic Technology Transfer''			+	+	+			
Adoption Pathway Cluster 2 "Community of Practice"		+	+	+	+			
Adoption Pathway Cluster 3 Hybrid of "Generic Technology Transfer" with "Customized (industry focussed) Service		+	+	+	+			
Adoption Pathway Cluster 4 "Generic Technology Transfer'' with "Community of Practice"							+	
Adoption Pathway Cluster 5 "Customized (industry focussed) Service" with "Community of Practice"							+	
Adoption Pathway Cluster 6 Multi-step process for Options 1,2 & 3 - "application driven CoP"							+	+
Adoption Pathway Cluster 7 "Farmer and market segmentation"	+		+	+	+		+	
Adoption Pathway Cluster 8 'Top-down' governance with participatory partnerships"		+						

+ - included all cattle producers as well as advisors, consultants and grains industry

+ - included large corporate graziers and then medium sized family enterprises

+ - included progressive producers & early majority

+ - Although ADOPT tool has predicted better uptake in northern beef, two CP members through focusing on the southern systems (whether beef or dairy) was useful because the advisory/consultancy system is more established, greater chance for observing commercial trials because farms are located closer together and good to demonstrate VHT value at a granular level (smaller resolution).

* - Assumption that all livestock producers (beef, dairy and sheep) were included in adoption pathway if not specifically singled out/specified

d) Entry point

- Multiple entry points for VHT adoption to raise awareness, interest and opportunities to evaluate the functionality and suitability include subsidized adoption campaigns, participation in VHT demonstration sites, invitations to join a CoP
- Once an adoption pathway has been started and sufficient time has been spent in the initial adoption phase, progress to one-on-one advisory services to develop a specific value proposition for on-farm trialling
-

Table 11: List of entry points for target audience to access an adoption pathway for each 'cluster'

Cluster No.	Entry Point
Adoption Pathway Cluster 1 "Generic Technology Transfer''	1. Fund producers through a campaign that has some sort of subsidy or freebie to garner interest. 2. Information campaign marketed through grower groups and/or industry bodies. The focus is to gain interest by these producer groups/industry bodies. 3. The hardest two parts of the process when starting from a zero-client base is getting a foot in the door, and then getting the technology to assert itself as a valuable asset relatively quickly. 4. Once a value proposition is established - build momentum through field examples, case studies – where the focus is on exposure.
Adoption Pathway Cluster 2 "Community of Practice"	1. These producers also have to be willing to trial the technology and accept any bugs or refining that is needed. 2. Producers need to be part of an adoption program/CoP whereby demonstrations on nearby farms can be used to show how VHT is run in a commercial setting. 3. An opportunity for producers to 'try' the technology [before fully investing]. 4. Marketing needs to be used but I think a mass marketing campaign will be wasted on such a targeted technology.
Adoption Pathway Cluster 3 Hybrid of "Generic Technology Transfer" with "Customized (industry focussed) Service	1. Industry Bodies involved supporting producers seeking to innovate and facilitated by agricultural advisers as a fee for service. 2. Start with two locations one in the North and one in the South, engaging existing networks to promote and educate producers/advisors and consultants. 3. Develop field days/ workshops through each state. 4. Develop a mass marketing plan from the lessons learned at the start from the small groups.
Adoption Pathway Cluster 4 "Generic Technology Transfer'' with "Community of Practice"	1. VHT Community of Practice, or direct invitation to establish producer technology demonstration groups/properties including Ag Bureaus, Improved grazing groups etc.
Adoption Pathway Cluster 5 "Customized (industry focussed) Service" with "Community of Practice"	1. Industry VHT awareness campaigns. 2. Demonstration farm model that is led by producer peer networks.
Adoption Pathway Cluster 6 Multi-step process for Options 1,2 & 3 - "application driven CoP"	1. Begin with the CoP target audience and work inwards as opposed to implementing at the producer level and driving the message outwards. 2. Invitation to be a part of an adoption program CoP.
Adoption Pathway Cluster 7 "Farmer and market segmentation"	1. Producers are all practical people so learn by seeing and discussing with fellow like-minded producers is the starting point. 2. Industry relevant awareness campaigns. 3. Establishment of commercial trial farms/demonstration field days/demonstration farms/Zoom sessions including interactions with the trial/demonstration farmer to endorse the product. MLA's Producer Demonstration Site (PDS) is a good example of participatory practice change designed to involve and partner. It allows a practice change to be trialled with minimal financial commitment. It can highlight limitations that can be addressed over the 3-4 years of the project before fully investing and adopting the change (technology). It also allows for regional application of the technology and surrounding producers can see how it is suitable to their properties with similar challenges. 4. Once this has been successful then the consideration for designing a PGS-like program to provide one-to-one practice change guidance for interested producers for their specific type of production system. 5. Value proposition according to their needs. 6. Provision of VHT extension services (public, industry and private sectors).

Cluster No.	Entry Point
	7. Work with people who have been engaged and supportive throughout the development of the technology.
Adoption Pathway Cluster 8 'Top-down' governance with participatory partnerships"	1. Work to change state legislation. 2. Support the development and availability of an experienced technical and advisory network as it will improve the successful use of the technology and help to manage the risks.

e) Adoption support roles and organisations

- Agersens/authorised retailers has a leading role in providing technical support and working in collaboration with other adoption providers, stakeholders and producer groups
- Agricultural advisers/consultants have a significant role to play in working with producers and the commercial developer as installers, coaches, expert advisers, technical trouble-shooters and product evaluators
- Government and R&D bodies have a role as regulators, coordinators and establishing product demonstrations
- Producers have a role in participating in VHT activities and sharing their experiences for peer learning

Table 12: Summary of key adoption support roles and list of organisations to be involved for each 'cluster'

Cluster No.	Roles	Organisations
Adoption Pathway Cluster 1 "Generic Technology Transfer"	1. VHT product information, knowledge and advice: the participants/producers need to see multiple benefits in their business that can be attributed to the addition of VHT, and that might even mean finding additional benefits beyond the initial scope. 2. Developing a strong value proposition: need to understand the issues or opportunities VHT will be addressing in their client's/farmer's business and they need to know how they are going to monitor it to ensure that the client can see on-going undisputable benefits.	It doesn't matter what organisation these people originate from as the messaging is the same, there is a lot of handholding when introducing technology.
Adoption Pathway Cluster 2 "Community of Practice"	1. Installation and implementation + coaching service/expert advice: helping producers with the initial setup and running of the VHT system on their property and using their wide industry links/coaching network if needed for additional/different support; producers rely on their trusted advisor who might (or might not) have experience with this technology. 2. Technical Support: someone ready to take a call from the farmer if they get stuck for follow up tech support where needed).	1. ag advisers/consultants and extension staff – first port of call 2. Agersens/commercial developer - second port of call however they tend to look at the technology in isolation, not within the farming system context
Adoption Pathway Cluster 3 "Generic Technology Transfer" with "Customized (industry focussed) Service	1. Government encouragement: current fed government ag minister is VERY focused on innovation in ag. 2. Whole industry support: no matter what the adoption program/strategy, need comprehensive support from the livestock industries. 3. State-scale coordination: need to engage agricultural retailers under the guidance of a coordinator to deliver training and marketing support.	1. Federal Government 2. Beef, Dairy, Sheep/cropping industries 3. Not explicitly defined
Adoption Pathway Cluster 4 "Generic Technology Transfer" with "Community of Practice"	1. Sharing experiential knowledge: it is the role of grower groups to share practical knowledge about experiences with precision agtech (including VHT). 2. Information dissemination including product review. 3. Supporting research and product demonstrations. 4. Changing state regulations: to permit VHT use on commercial farms. 5. Training VHT advisers/resellers: a commitment would need to be made to upskill people to provide competent service in this space. 6. Conducting product trials and supporting farmer group activities: as part of a general role of reviewing alternative fencing products.	1. Grain Growers, No-Till farming groups (SANTFA) etc. 2. VHT retailers and manufacturers 3. RDCs - have a direct obligation in this role 4. State Governments 5. Not explicitly defined 6. VHT suppliers/Technology Influencers
Adoption Pathway Cluster 5 "Customized (industry focussed) Service" with "Community of Practice"	1. "Seeding" the technology: introducing and embedding the technology into mainstream farming systems with merit in industry specific "seeding" which would also build trust. 2. Demonstrate Proof of Concept: target certain applications within industries to prove the concept in the least risky way first up.	1. Not explicitly defined but response suggested industry organisations? 2. Not explicitly defined but response suggested industry organisations?

Cluster No.	Roles	Organisations
Adoption Pathway Cluster 6 Multi-step process for Options 1,2 & 3 - "application driven CoP"	1. Ongoing scientific trials: challenging or unproven applications are scientifically evaluated in a controlled research environment prior to adoption of the applied research being undertaken directly on commercial farms. 2. Application endorsements: The path for proven applications goes from individual farm to groups of farms which is co-supported by independent advisor/s who are endorsed as part of the CoP.	1. Not explicitly defined 2. Producers/independent advisors as a VHT CoP
Adoption Pathway Cluster 7 "Farmer and market segmentation"	1. Shaping farmer views: through Key Opinion Leaders. 2. Awareness and interest raising: information dissemination, the location of demo farms, case studies of real-life applications and contacts to find out more information or buy the products through campaigns and social connections. 3. VHT access: provide product access at retailing points. 4. Implementation know-how: technical assistance and expertise. 5. Farmer/end-user training: VHT software and hardware management training must be provided to ensure users are aware of the limitations of the product. Poor understanding of setting virtual fences or herding the animals from one point to another could compromise animal welfare. 6. On-ground support: ongoing support will be required, as what is intuitive to some isn't to others and there will always be questions regarding troubleshooting; once the technology is rolled out, there will be constant ideas and requests for additions to functionality and further uses. It will be important for "adoption support teams" to know what improvements are scheduled next, what is in the pipeline and what would be cost prohibitive or wouldn't work to manage expectations.	1. VHT Trialist 2. RDCs, government and producer networks 3. Distributors and retail networks 4. Agersens 5. Not explicitly defined 6. Not explicitly defined but agricultural advisory consultancy firms were listed as providing adoption support
Adoption Pathway Cluster 8 'Top-down' governance with participatory partnerships"	1. Guidance and duty of care: stewardship roles for industry bodies. 2. Developing support networks: support the development and availability of an experienced technical and advisory network as it will improve successful use of the technology and help to manage the risks. 3. Relationship building: The development of advisory networks should be conducted as part of a participatory process during the early adoption stages. A constructive partnership with the technology owners/commercial providers will be critical.	1. Livestock industry bodies 2. Not explicitly defined 3. Producers, agricultural advisers and the commercial developer

f) Funding model or investment required for adoption

- Too early to invest in an adoption pathway – need more time to build evidence of successful commercial use
- "All hands-on deck" across the VHT innovation and adoption system to invest time, money and other resources for research trials, demonstration farms, and other strategies to strengthen the value proposition
- Perhaps rethink a fully commercial model for adoption support and product access

Table 13: Funding model or investment required for each 'cluster'

Cluster No.	Funding model or investment required
Adoption Pathway Cluster 1 "Generic Technology Transfer"	Not explicitly defined
Adoption Pathway Cluster 2 "Community of Practice"	Too early for livestock industries to invest in VHT adoption • No guarantee this technology will be widely adopted by a majority of livestock producers. • Need to focus on the innovators and early adopters first to provide evidence that it will work or wait until it can be delivered as an ear tag. More investigation might be needed to develop the right business model • Charging for the device, software subscription and fee for service support may not the best way to do it.
Adoption Pathway Cluster 3 Hybrid of "Generic Technology Transfer" with "Customized (industry focussed) Service	Investment in group-based adoption programs • Investment in Producer Demonstration Sites to showcase applications and help promote and develop the VHT adoption program. • Farmer levies or co-contributions.
Adoption Pathway Cluster 4 "Generic Technology Transfer" with "Community of Practice"	Comprehensive investment • Suppliers/Technology Influencers – majority of trial funding should come from the commercial realm, although this may be challenging. • RDC's –provide source/seed funding to grower groups/properties wanting to demonstrate the technology. • Government – some kind of compensation to be provided; access to government funds would likely be via producer paid levies. • Producers/Farmer Groups – contribute via levy payments for research capabilities. If clear value proposition can be articulated – increased investment would be anticipated. • Advisors/Resellers – would expect some level of financial contribution from each entity if it is anticipated that they will generate additional revenue from increased adoption.
Adoption Pathway Cluster 5 "Customized (industry focussed) Service" with "Community of Practice"	Not explicitly defined.
Adoption Pathway Cluster 6 Multi-step process for Options 1,2 & 3 - "application driven CoP"	Resourcing the VHT CoP • The CoP needs resourcing to make it happen and then resourcing of the adoption pathway against the desired outcome will be an evaluation/recommendation by the CoP or a subgroup of CoP with the required expertise and skills to make this evaluation.
Adoption Pathway Cluster 7 "Farmer and market segmentation"	Commercial model • Trial and Buy. • Credit to the life of the product. • This is a commercial product to which one company has the rights - Agersens would be responsible for the lion's share of investment in adoption as they will be retailing the product.
Adoption Pathway Cluster 8 'Top-down' governance with participatory partnerships"	Not explicitly defined.

g) Comments on how to progress the 6 Key Considerations

- More clarity is needed around the value proposition to include risks, multiple stakeholder benefits and core functionality – this will help in managing farmer expectations about what VHT can do for their business, natural resources and farm productivity
- Enrolling adoption support beyond the commercial developer could be a challenge for a few reasons: not all production regions are serviced by a large pool of agricultural advisers/consultants for on-farm support; need to build the knowledge/experience base of VHT adoption providers to deliver a quality service and it is difficult to build an effective VHT support network when there are competing interests between agricultural advisers/consultants, their farmer clients and the agtech market, which is saturated with new products – complex decision making environment
- Regulation of VHT use as either best practices or quality assurance programs will be important to manage risks and incentivise producers to use VHT for premium farmgate prices and public goods

Table 14: Summary of comments on how to progress the 6 Key Considerations

Key Consideration	Suggestion for progression
Key Consideration 1 Anticipated Benefits	• Major barrier to successful adoption is a poor understanding of the technology capabilities and/or its requirements. The challenge is to harness farmer enthusiasm and innovation, whilst avoiding the biggest risk which is wrongly challenging the technology and getting an adverse outcome. This risk must be mitigated in any adoption pathway. • Poor or wrong expectations in many cases driven by overpromising or sales pitch, or due to immaturity of the technology, might lead to failed adoption and producers losing interest or faith in the potential of those technologies. • There has to be a bit more clarity not only on the cost, but on the benefits. The fact that technologies have the potential to bring certain benefits, doesn't mean that every farmer will or can achieve those targets. Producers need to understand this. • There are major opportunities for use on non-farmland, public land and for public-good purposes (e.g. vegetation conservation, revegetation, weed management, protection of environmentally sensitive areas). Public land managers or those leading environmental initiatives will likely require a different approach to adoption support, compared to the commercial graziers.
Key Consideration 2 Value proposition	• In essence, the BCA is traditional fencing vs. using VHT, but the core functionality isn't super clear. • In some way 'risk' of adopting this technology, or if it fails, needs to be captured in the value proposition. • If return on investment depends on technology being applied as 'multi-purpose', then what happens if there is a staged approach (in either functionality or scale) to adoption? • Clear value proposition for all stakeholders (direct and indirect) is required. • Needs demonstration of ROI.
Key Consideration 3 Adoption support	• The biggest issue is adoption support and ensuring there are enough knowledgeable people to make sure VHT issues are addressed in a timely manner. This is one of the biggest issues holding back tech adoption. Part of my work is helping contractors with variable-rate fertiliser and the use of ag tech is still the biggest hurdle. Even though the process is quite simple, small issues bring the whole operation to a standstill. This is why I think it's so important to have as many of the issues or potential ones resolved before there is widespread uptake. This can't be a product that has problems resolved 'on the go' as producers will soon become frustrated, even if it offers production gains. Hopefully this is where a CoP can help by having these discussions early on, with producers and stakeholders getting some of the bugs out of the system early. • The capacity in Northern Australia to support extension and adoption is not present. Investment would be required to upskill young graduates and provide an attractive package to relocate to the north to undertake this type of work. Government extension employees are already stretched thinly across the north and have a myriad of duties and commitments which would make their participation limited. • How can you effectively engage a support network that has different core businesses and that might not have the time (or interest) to engage with these developments. For example an agronomist can potentially benefit by suggesting the producers they work with to adopt this technology that will enable better utilisation of pasture, but there is a competing factor of this technology with pasture varieties, devices to measure pasture volume, quality, soil moisture, etc. So the agronomist will have to choose. Today there are too many technologies.
Key Consideration 4 Big Data governance	• Need to understand a bit more about the data side of it. What type of data is produced, with what resolution, how identifiable it is, what could others potentially do with it?

Key Consideration	Suggestion for progression
Key Consideration 5 Maintaining social license	• Accreditation of producers will ensure that animal welfare concerns are met, and that adoption of sustainability initiatives is driven by the ability to improve productivity and profitability of the new system.
Key Consideration 6 Regulation of VHT	• It will be key to show that animal welfare is front and centre in the success of this program. • Best practise/guidelines to implementation are critical for adoption increases. • Looking at risk-regulations, what happens if the technology 'fails' and animals leave the exclusion zone and cause damage or an accident. Who is liable for that? This needs to be thought of, because even physical or electrical fences have failed, and this has been an issue. • Accreditation program, to provide producers with a method to capture and record current sustainable practices happening on-farm (e.g. an online self-assessment tool). This requires a clear value proposition to be articulated to producers to incentivise engagement – this could be identifying opportunities to improve productivity/profitability through implementing new or different sustainable practices. • VHT Best Practices are not readily available and is limited by state legislation [currently VHT can only be used commercially in New South Wales, Queensland and Tasmania]. Any trial farm should demonstrate KPI's or VHT [Best Farm Management Practices].

h) Other key considerations or missing components to the VHT adoption pathway

- A new approach needed for VHT adoption – standard adoption approaches are unlikely to result in significant uptake of this technology
- More work needs to be done on how VHT integrates with other precision agriculture technologies/systems at both the technical and data analytical levels
- Producers will need training and upskilling to build their knowledge and proficiency in using VHT – VHT will not automatically create better producers!

Table 15: Summary of other key considerations or missing components to the VHT adoption pathway

Other key considerations or missing adoption pathway components
New adoption pathways needed: flexible, application driven and farm-scale
• New and innovative adoption models are required to replace the traditional extension models based on research conducted at research stations and 'dissemination of research' based on extension agents. • Need to get agreement on a general approach to determine the pathway that is application driven focussing on proven applications rather than unknown applications. • Can we map somehow a recommended adoption path on-farm? Can we link this to management practices or decisions on-farm as well as to other technology that producers might look into? So for example we recommend you start with internal strip fences in young calves and progress to all fences, we recommend you adopt this technology after one that measures pasture availability.
More trialling to represent the diversity of livestock production in Australia
• VHT needs to be trialled under more commercial settings across Australia in different environments to allow producers to make a more informed decision on the appropriateness of this technology to their property.
Greater focus needed on farm system integration
• More emphasis on alignment and integration with other technologies and farming practices. These would be industry specific in most cases, but it is not often any new technology is or can be seen in isolation. • One that has been mentioned but I think not in depth is the integration with other technologies on-farm as well as staging the adoption. • Would suggest the possibility of integrating this technology with others that are collar based (identification, activity, rumination for example) in order to make it easier but also enrich the potential value of combining data.
Who carries the financial burden when there are multiple beneficiaries?
• If the technology can potentially bring benefits to multiple stakeholders, who is going to pay for the upfront and ongoing cost and maintenance of it? • Define disconnections with supply chains.
Evolving value of VHT
• The value of the technology might be in areas that have not yet been explored (individually grazing cows for example).
AMS as a case study for VHT?
• From our AMS (~Automatic Milking Systems) experience, there is a lot of information available, but not every farmer goes deep to try and understand all the intricacies before they take a decision. For AMS we constructed 'Milking Edge' as a project that helps producers CONSIDER-INVEST-OPERATE. This is somewhat similar to this framework.
Learning model from MLA
• Profitable Grazing System program could be used as a basis for developing a VHT learning model to support the livestock industries by educating and supporting producers/advisers in [precision livestock management].
Farm management skills will determine the success of VHT
• It has to be clear that technologies like this one are tools or enablers. They do not turn poor managers into good managers. In many cases they even highlight poor management. • Producers will have to learn new knowledge and skills and will have to adapt their management practices on-farm. How much? That will depend on what they try to achieve, the starting point and the stage of adoption. They have to understand this and try to either upskill or build support networks around them to ensure they are successful. • People take different amount of time to transition. Some do it very quickly whereas others take a couple of years to do it. • Define producer knowledge/capability gaps.

APPENDIX 3 – LIST OF ANTICIPATED VHT APPLICATIONS & BENEFITS

A comprehensive list of the anticipated benefits and application of VHT according to the livestock producers who participated in our 2017 workshops

Responses from multiple workshops	IMPROVED LIVESTOCK MANAGEMENT • Farmers can manage livestock in a timely and informed manner through the VH technology alert system and activity meter i.e. real-time decision making • The ability to monitor health (heat sensors, heart rate) activity patterns (e.g. grazing, rumination, resting) and access to pasture (e.g. minimizing the risk of nitrate/nitrite poisoning in dry periods) of every animal through the collar means improved management of animal welfare and a reduction of deaths • Potential weight gain of animals from higher intake of pasture contributing to animal health • Identifying desirable genetic traits for selective breeding (e.g. identifying feeding efficiencies and conversion to quality meat/wool production in certain animals; identify cows with shorter gestation periods) • "Roll-call" of livestock i.e. real-time mapping of livestock locations, which can assist with achieving "clean" musters • Valuable application is sub-herd management (e.g. controlling and tracking bull/cow pairings) • Dropping the virtual fence in times of emergencies (e.g. bushfire event) allows animals to move to safety because there is less internal fencing
	IMPROVED PASTURE MANAGEMENT • Intensive grazing regimes e.g. cell, rotational, strip, allow for better utilization of pastures and fodder crops that are typically larger paddocks with little physical fencing • Better pasture management can lead to higher stocking rates through efficient grazing regimes and excluding grazing from degraded areas
	MANAGEMENT OF DIFFERENT LAND CLASSES FOR ENVIRONMENTAL/ECOLOGICAL OUTCOMES • Protection of waterways and regeneration of vegetation areas considered having conservation value • Excluding livestock from high erosion areas reducing the incidence of erosion in vulnerable areas • Better integrated management of cropping and livestock enterprises e.g. targeted management of failed crop areas i.e. using VH system to control grazing in these areas may mean less herbicide use
	FLEXIBLE LIFESTYLE • Being able to manage livestock remotely (from a distance or off-farm) through the VH technology alert system and activity meter capability (e.g. farmers knowing when livestock "break" a virtual fence or if an animal is ill/distressed indicated by heart rate readings or has died indicated through an inactive collar)
	SOCIAL SUSTAINABILITY OF THE LIVESTOCK INDUSTRY • VH technology could attract a new generation of farmers to the livestock industry and retain current beef, dairy and sheep farmers because the system enables a more flexible lifestyle through remote or more convenient/physically less demanding farm management; provide more opportunities for share farming or farming leased land where there is little fencing infrastructure; promotes livestock farming as innovative and contemporary by digitizing livestock management • VH system could generate enough profits to employ extra farming labour, support more farming households or shift labour to other parts of the farming business therefore benefits do not have to be framed as reducing labour costs
	COST SAVINGS • Reducing costs of material and labour involved in installing, maintaining, relocating and repairing physical fences

	• Protect existing fencing infrastructure by better control of livestock movements and reducing incidences of feral animals damaging fence lines • Less money spent on pasture renovation through better pasture management • Reduced labour for mustering (sheep and northern beef) • Collective purchase of base station to be shared across two adjoining properties
Distinct responses from Southern Beef workshop	REDUCED FENCE MAINTENANCE • Less worry about fence damage caused by the movement of kangaroo mobs and fallen trees
	IMPROVED PASTURE MANAGEMENT • More effective management of the impacts of pugging during the wet months
	IMPROVED LIVESTOCK MANAGEMENT • Better control of livestock overall could assist with targeting specific meat markets
	FELXIBLE APPLICATION OF VH SYSTEM • VH system can be applied through a staggered approach – virtual fence can replace physical fence one paddock at a time
Distinct responses from Northern Beef workshop	IMPROVED LIVESTOCK MANAGEMENT • Better management of bulls by ranking herd in terms of efficient bull performance • Minimize disturbance of herd when moving individual animals or sub herds • Herd class segregation
	REDUCE PRODUCTION COSTS • No need for flood fencing
	ADDED VALUE TO SELLING LIVESTOCK • Heifers that are VH trained could be a selling point
Distinct responses from Dairy workshop	FARM SAFETY • Avoids having to expose farmers/farming staff to the risky practice of installing and maintain physical fences in steep, hilly country
	IMPROVED LIVESTOCK MANAGEMENT • Improving animal productivity through a more finely tuned approach to nutritional management and efficient use of supplementary feeding for individual animals and large milking herds • Possibility of reducing feet soreness • Improved management of livestock on a turnout block • Improved utilization of milking plant
Distinct responses from Sheep workshop	IMPROVED LIVESTOCK MANAGEMENT • Selective mustering of rams in relation to main herd • Being able to plan the efficient movement of stock to shelter or shade based on weather forecasts • Potential to move stock slowly for marking
	FARM LABOUR PRACTICES • VH livestock managers could be employed across different farm properties and manage livestock on a per herd/paddock basis
	FARM BUSINESS MANAGEMENT • VH system could be used for inventory control, which could be useful when applying for a financial loan
	IMPROVING GENETICS OF SHEEP HERDS • Famers could provide feedback on genetic traits to stud breeders – (Australian Sheep Breeding Values) • Increase credibility of stud farms
	CLIMATE CHANGE MITIGATION • Assist with managing carbon emissions intensity from efficient grazing/pasture management
	WILDLIFE WELFARE • Lack of internal fencing allows wildlife more free movement across the landscape • Reduces loss of wildlife from being injured and ‘caught’ by fences
	INDUSTRY GOODS FOR LIVESTOCK STOCK INDUSTRY

	• If data is collected and aggregated across VH farms the livestock industry could benefit from a comprehensive understanding of livestock behaviour and grazing patterns and predictor of meat and wool yields • Wide adoption of VH technology on-farms could assist with biosecurity i.e. early warning of disease outbreaks • Improve the management practices of 'middle-grade' producers reducing the death rates of livestock, which would be a key message to promote to the public • Such industry-wide knowledge could become a competitive advantage for Australian agriculture

7.6 Technical Notes

A series of 10 technical notes that provides technical information about Virtual Herding (VH) technology and how it may be used by the Australian livestock industries, including the results of some of the R&D conducted in the Project as case studies have been produced. The following series of stand-alone documents provide a legacy of some of the main achievements from the VH Project. This series of Technical Notes include:

1. Introduction to VH technology.
2. Welfare assessment of applying VH technology in cattle.
3. Factors affecting the response to virtual fences.
4. Use of VH technology to improve pasture utilisation.
5. Use of VH technology to herd animals.
6. Use of VH technology to control sub-herd livestock management.
7. Use of VH technology for environmental outcomes.
8. Use of VH technology in the sheep industry.
9. Break-even cost analysis of the implementation of VH technology in the livestock industries.
10. Adoption pathways for VH technology.

Copies of these Technotes are made available to the Department of Agriculture Water and the Environment and each of the 10 Project Partners as well as members of the Project Steering Group. Copies of pdf versions of these Technotes will be available from the Dairy Australia website at: https://www.dairyaustralia.com.au/feed-and-nutrition/current-research/smart-farms/virtual-herding#.X6R4ZizivIU