

Understanding pathways of digital technology development to improve farm sustainability and resilience

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Abstract

We explored potential pathways of digital technologies to improve both resilience and sustainability outcomes in grazing systems by investigating the development requirements of virtual herding technologies. We used a Lead User group familiar with virtual herding technology to examine the question “after virtual herding has been successfully adopted, what will the future look like”? This group included agribusiness, industry, corporate farm management, farmers, and science. A brainstorming approach generated ideas. A horizontal prototype was built by clustering ideas into themes of the technology itself, requirements of people, applications, and outcomes, allocated to short-, medium-, and long-term timeframes. Steps required for technology development included: production of a minimum viable product, integration of sensors, and the addition of landscape digitisation. The requirements/impacts on people identified training and awareness, development of skills and labour requirements, and the changing roles of people in the landscape as a progression of change. Applications included productivity, environmental protection, landscape development and enterprise change. A range of requirements were identified within each of these steps and categories. The development of a vision of future technology use provides insight into the complexity of developing digital technologies for sheep and beef farming applications.

Keywords: development, digital, people, technology, transformation

Introduction

Implementation of digital technologies at a task-based level on-farm, such as weighing systems and milk measurement is relatively straight-forward. However, integrating digital technologies to transform farming is more complex. In dairy farming, Dela Rue et al. (2019) found that farmers preferred simple automation technologies such as automatic cup removers over technologies that supported decision making such as walk-over weighing. For red meat farming in New Zealand there has been little research done or tools available for whole farm management of the large mob sizes and spatial scales at which sheep and beef farming operate.

To support decision-making and transformation, a range of technologies are required, operating at different time and spatial scales. They may be used to characterise the resource, predict future performance or as monitoring tools (Balafoutis et al. 2020). A crucial element to deliver success is control, and in the case of livestock farming the development of virtual herding technologies can control the most important mobile element, the animal. This step is crucial as an enabler to allow management decisions to be implemented on appropriate time and spatial scales to deliver improved outcomes.

The introduction of any new technology to improve farm management needs to be carefully assessed to ensure that the overall system is not compromised (Jago et al. 2013). Assessment of new technology can be difficult, and the process can extend over a considerable amount of time from concept to commercialisation of the product. The assessment process for virtual fencing (VF) has been a long journey. The first patent for a VF technology was filed in 1971 for use in dogs, with the commercialisation of a VF for ruminant species occurring much later (Umstatter 2011). Patents filed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Lee 2006; Lee et al. 2010.) have been commercialised by Agersens (Campbell et al. 2018) in their eShepherd™ technology, creating the first commercially available GPS-based virtual fencing systems for large ruminant livestock. The eShepherd™ system utilises GPS technology in conjunction with an audio cue to indicate the proximity to the VF boundaries, with an electric pulse to deter the animal from crossing that boundary in a similar fashion to traditional electric fences. This system has undergone extensive research on individual and small groups of cattle in Australia investigating the animal welfare implications, such as exposure to the pulse and audio stimuli, and learning behaviours such as the length of the learning process (Campbell et al. 2017; Campbell et al. 2018; Campbell et al. 2019; Lee et al. 2008; Lee et al. 2009; Lee et al. 2018).

As beef cattle grazing systems are a critical part of effective hill country management and are under threat through potential water quality regulation, we explored the potential of virtual fencing and its application as an example of a critical digital tool. Creating an

understanding of the potential progression of this tool provides insight to increase the effectiveness of development and application of digital tools for both developers and users. An approach similar to that recommended by Eastwood et al. (2021), engaging use of responsible innovation processes and anticipation of alternative futures, was used to support reflection on technological trajectories and the development of associated technologies that may be required to support transformation. We aimed to develop a vision of the progression of virtual fencing uptake and application as the technology becomes commercialised.

Materials and Methods

The project used a horizontal prototype development process (Carr and Verner 1997), engaging a Lead-User group to examine the question 'After VF technology has been successfully adopted, what will the future look like?'. The target was specifically beef cattle producers, rather than dairy farmers, with the available virtual herding technologies only applicable to cattle at this stage.

A Horizontal prototype is a term used in software development that displays the user interface for the product and gives a broader view of the entire system, without concentrating on internal functions (Kensing and Munk-Marsden 1993). Horizontal prototypes are used to get more information on the user interface level and the business requirements. The Horizontal prototype approach is used in this context to convey the broad vision of implementation of virtual herding, rather than detailing the needs and events that may happen over time.

The Lead User Method (Luthje and Herstatt 2004) engages with advanced users or users who deal with a problem very intensively in a certain area. Lead users are often early adopters of new methods, products, and technologies. Their needs and choices usually portend the needs and choices of the general market and provide significant opportunities for introduction of innovative products (Brem et al. 2018). This process is similar to the Delphi process, developed by the Rand Group in the 1950s as a method of trying to reach a consensus when forecasting technological impacts on warfare (Helmer, 1967). The Delphi method has been described as particularly useful for predicting future uses of technology and social changes (Brady, 2015).

A group of 19 Lead users were engaged in a workshop (17 October 2019) to examine future potential uses of virtual herding technologies in transforming livestock farming in grasslands. The Lead user group represented Agribusiness (4), Industry (3), Corporate farm management (3), Farmers (4) and Science (5).

Development of the Horizontal prototype

The topic of the future when virtual fencing was adapted was examined using a modified four windows approach

(Flood 1999). This systems-thinking approach poses four viewpoints of an issue to create unique insights to the topic. This then provides a more holistic development of the course of action and potential transformation that may occur (Flood 1999). Similar to the Delphi method, this provides an iterative approach to developing a consensus of ideas while strengthening the outcomes (Hasson et al. 2000).

This approach was applied during the workshop using the viewpoints of Production, Environment, Landscapes and Enterprises. The production lens was targeted at the specifics of increasing productivity characteristics such as stocking rate, per animal performance and cost saving. The environment lens targeted the primary outcome as improving environmental outcome of livestock farming such as water quality, sediment loss and greenhouse gas emissions. The landscape lens focused on landscape amenity and visual appearance, including potential impacts on the user experience of the landscape. The enterprise lens examined the technology from the view of its potential to alter the types of enterprise, such as store, finishing, red meat, dairy, horticulture etc., that may be able to be implemented at the on-farm level. Each topic was examined by first identifying the potential impacts of technology application, imagining the outcomes required and then defining the mechanisms that would be required to achieve those outcomes. Themes were collated using future time frames as an imagined implementation pathway. As the workshop progressed a narrative of continued development was accompanied by expanding understanding of potential uses and increasing needs for social engagement. This narrative is documented to illustrate the thinking process and the evolution of ideas and applications for virtual herding technology, as captured in the four viewpoints that were taken.

Outputs from the workshop were then combined with team brainstorming to develop separate horizontal prototypes for technology development and people requirements.

Results and discussion

The results from the workshop process provided a range of data which has been collated in several ways. The first is in a narrative that represents the opinions of the workshop participants. Some data is collated into a table for specific representation of potential development over time. As the innovation timeframes are future-focused, the associated narratives cannot be tested, and so are represented as statements that summarize the thoughts of the participants.

Narrative

Early adopters

The emerging narrative from the workshop began by identifying early adopters in hill country taking up the

technology for the specific task of replacing waterway fencing, targeting a single stock class where success was demonstrated. This would include large/corporate farms, those who need to control cattle near complex waterways, those who need to replace existing fencing infrastructure, and those who have little infrastructure and want to improve grazing management. These will also be technology-literate farmers or those with access to a support network.

Risks

In this initial stage it was identified that there were significant risks as the technology is adopted. Failure of the technology to deliver a minimum viable product in a timely fashion was the first of these. Another was the overenthusiasm of the user who may extend the use of the technology beyond its capacity to control animals and cause technology failure. This type of threat is a significant reputational risk. Public opinion may drive a backlash against the technology through animal welfare concerns. Some social media channels are recording this type of sentiment at each mention of the technology in the press. The training requirement for implementation may be too great (Duffy et al. 2021). Technically competent staff may be needed to keep the technology going. A high service requirement to create the virtual fences and to keep the technology running would reduce its effective uptake. Virtual herding is likely to generate some levels of intensification. This may then encounter restrictions from the regulatory frameworks.

Development of impacts over time (Table 1)

Impacts (Table 1) were identified during the workshop process and, as these emerged, a narrative was developed to explain that impact. A set of near future users were identified. These included regenerative grazers and hill country farmers under pressure to fence waterways. Value chain biosecurity systems such as the National Animal Identification and Tracing (NAIT) could be enabled through the unique identifier in each virtual fence collar.

The virtual fencing system, with its alerts regarding animal whereabouts and activity may reduce farmer stress through surety of livestock placement. As the software and data interpretation increases, animal health and well-being may be built into the reporting options back to the farmer, further increasing peace of mind, and early diagnosis of potential animal health issues. Additional technologies such as proximity sensors to predict mating events and dam/calf interactions, including parentage may be added. Algorithms may be developed to predict greenhouse gas (GHG) outputs based on grazing and rumination behaviour.

At the environmental and landscape scales the control of animals should result in improved water quality. There may also be a lower need for winter

crops as pasture utilisation increases, with potential increases in pasture production because of lower dead material accumulation (Thompson et al. 2017). As the technology improves, control of intake on crops can be achieved through greater animal control, again with the potential to increase utilisation and reduce the amount of winter crop required. Finer control of animal movement will increase the understanding of a range of uses as farmers experiment with the technology. This will have the potential to enable the development of tailored grazing plans for parts of the herd, even when grazing in the same physical paddock, providing individualised nutrition within the grazing herd. This level of precision grazing would allow dairy and beef herds to be used in more situations such as weeds control, provide tailored nutrition in droughts and to utilise standing hay to reduce fire risk. Development of finer control will also result in herding options where animals are moved remotely from site to site, allowing for a reduction in labour requirements.

Future uses

The time frames allocated to the development of impact (Table 1) provided a framework for thinking and are represented here as emerging opportunities, rather than documented to any specific part of that timeline, recognising that capturing of opportunities will depend on the engagement of people. As the technology matures integration with other data sources may be possible. Links to pasture measurement techniques, both quantity and quality, may mean that animal nutrition is optimised for any situation, both at herd and individual levels. Protection of biodiversity will be enabled by the introduction of exclusion zones within grazing areas. At the on-farm level livestock exclusion zones can be revegetated with native plants, encouraging wildlife corridor development, and grazing management control can enhance pasture biodiversity. This may also apply to areas of spiritual and cultural significance. This type of approach may also enable the provision of safe access for the public into areas where animals are being grazed.

As the technology becomes more automated, with, for example, pasture measurements driving the placement and movement of animals, more time will become available to do other things as grazing plans are implemented remotely. This then provides more opportunity to invest in other enterprises (due to more time). This freeing up of time is an important element in facilitating innovation and enterprise change. Reduced chemical inputs on-farm will be possible as weed control is more achievable with grazing. As the virtual fencing technology evolves then sheep and deer may be added to the animal species which can be virtually herded.

The concept of community engagement may produce the development of co-grazing where the control

enabled by virtual fencing allows animals to enter spaces that were previously unavailable for grazing. This may be extended to engagement with regional and national government agencies (e.g., Department of Conservation) to implement targeted grazing plans in sensitive estates (e.g., bird breeding areas that need open spaces created by grazing).

With the addition of other types of sensors, automated reporting may provide active confirmation of the improvements in environmental and animal management. This may include compliance with winter grazing regulation, provided through animal placement records. The welfare and health of the animal will be monitored and so that data will become proof of good animal husbandry. These types of metrics are already incorporated into quality assurance schemes in the red meat industry. Current practice is to document activities which are then checked through an audit process. This type of wearable technology provides the opportunity to collect this type of data at an individual animal scale automatically. This will assist with proof of welfare for regulatory compliance and consumer assurance.

As these opportunities become realised and socialised a new type of entrant to agribusiness may appear as technology driven businesses and people engage with farming, through the technology. This then may lead to changes in farm management structures as technology providers add multi-farm services for technology maintenance, delivery, and decision-making. The realisation of these types of interactions between agribusiness and technology may bring consumers shareholders and stakeholders together and result in greater interaction through potential hyper-transparency, provided by internet availability of the information provided by the collars.

Fine scale control of the grazing animal may create opportunities for horticulture, arable and tree crop enterprises to potentially be able to be incorporated into a livestock farming system. Conversely, livestock can be more easily incorporated back into arable and horticultural systems. This then may lead to new business models as specialists in livestock can apply their skills into other enterprises and vice versa. Increasing complexity of each enterprise has led to specialisation and a reduction in the diversity of enterprises on-farm (Noe and Alroe 2012). The ability to use virtual fencing as a remote technology would allow graziers to apply their specialisation to cropping and horticultural systems without the need for those farmers to upskill in livestock management. Reducing the need for fences, and managing livestock remotely, using the range of potential added technologies, such as pasture mass and quality measurement would allow the additional utilisation of cropping and horticultural systems for livestock farming.

The skill sets across the community may increase as the type of technology and range of enterprises expand.

The technology will need support and the development of expert users. This may be within the farming family, providing a greater range of roles for new skills. It may also be in the development of new local business models of technical support. As these opportunities develop, we may see changes in the farming model with a community of farming developing. This may lead to a rise in other technologies and value chains such as mobile meat processing, promoting a lower footprint for the value chain (e.g., only transporting the carcass, rather than the whole animal). Road-side grazing models were identified. This would allow utilisation of forage at critical times, reducing the need for roadside control of foliage and reducing fire risk. This would reduce inputs from mechanical intervention with all the associated reduction in labour, capital, fuel and pesticide use.

Horizontal prototypes of technology development and people

The development of the narrative identified that the risks provided a route to develop successful technology implementation (Figure 1). As the prototype was developed the role of people (Figure 2) emerged as needing to be synchronised with both the technology development and its use. The first step was identified as the demonstration of a successful Minimum Viable Product. This may entail ensuring that specific criteria are documented to define the boundaries of the technology application. The purpose of this would be to limit the potential to over-reach the capability of the technology. This may be managed through the selection, support and coaching of appropriate first users of the technology (Figure 2).

Educational packages were seen as a vital part to support existing users of the technology, including support from management when staff are involved. The option of providing instruction on the technologies use in current secondary and tertiary training was recognised. This would ensure that future users are familiar with the structure of the hardware, firmware and software of the technology. Finally, the development of on-line support could be developed for both technical and social media. This was suggested to ensure that a repository of knowledge was available for self-learners.

Further technology development occurs by expanded understanding of when the technology fails. A technical support team is required to investigate and document the failures of the technology. Often early failures will be contained within a beta testing programme. However, early adopters will extend the potential applications of the technology, creating conditions of potential failure. Early promotion and training needs to provide practical demonstration of all the situations where the technology works. It was suggested by participants that another step to ensuring that the technology develops alongside user experience was to create a network/user

Table 1 Impacts from the application of virtual herding technologies on productivity, the environment, the landscape, and enterprises over short (1-2 years), medium (2-5 years) and long term (5-10 years) timelines.

Timelines			
Window	Short term	Medium term	Long term
Productivity	Reduced fencing costs and needs	Managed pastures to increase pasture harvest	Breeding decisions
	Evidence of animal location	Better use of forage resources such as crops Automated creep feeding of priority stock	Phenotypic capture for genetic improvement Feed conversion efficiency used for culling
Environment	Waterways protected	Match of animals to feed quality Proactive/targeted animal health	Links to remote sensing technologies to manage feed supply Improved biodiversity
	Management of crops such as plantain to increase application of mitigation	Less supplementation and more use of home-grown feed	
	Deliberate management of stock camps, wetlands and buffer strips	Lower nutrient losses Integrity of plantings and biodiversity corridors	
Landscape	More grass on waterway margins	More defined specialist grazing species/ areas	Changing livestock classes seen (more dairy beef) Fewer fences
	Higher animal densities for shorter times	Shade and shelter provisions	
	More troughs and water supply systems Less mud	Riparian areas defined with seasonal grazing in dry periods Less weeds More trees Changing utilisation of hill country and associated colour change from brown to green	More alternative land uses Retirement of land More birds and trees More natural landscapes
Enterprise	Protection of archeological, biological and sacred sites	Farming of cattle can continue	Precision management of landscapes with animals integrated
	No fences in sensitive areas	Animals managed in a more free-range approach and more specialist forage use enabled	New and different enterprises within traditional animal landscapes
	Exclusion from gateways in wet conditions	Cropping enterprises can be sited within sensitive catchments	More diverse landscapes where animal are matched to other enterprises
	Reduced costs of fencing waterways	Larger open spaces and no gateways to restrict mechanical operations	
	Reduced vehicle movement and associated labour, R and M and capital requirements	Adjustable and flexible enterprises without fencing constraints	

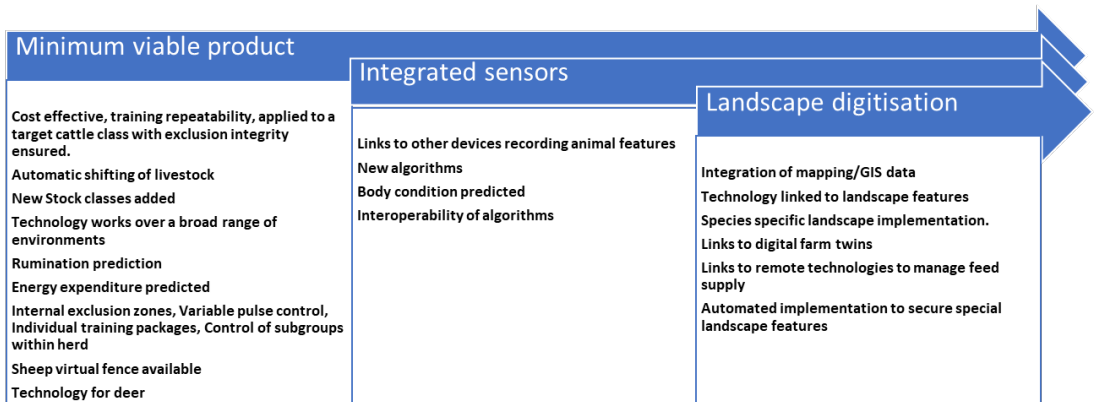


Figure 1 Horizontal prototype of technology development with indicative timeframes moving from short to long term, from left to right.

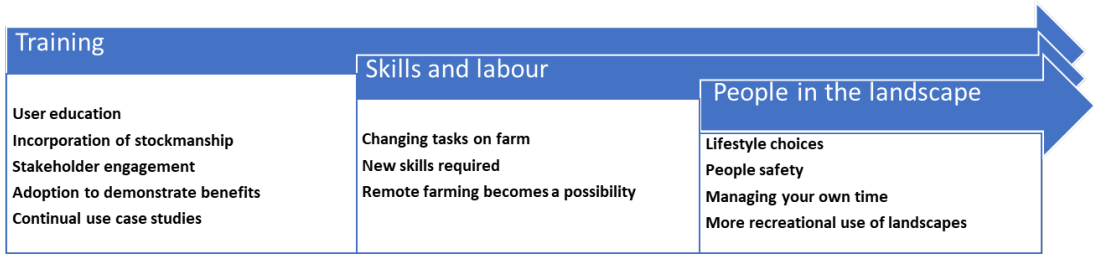


Figure 2 Horizontal prototype of the role and requirements of people with indicative timeframes moving from short to long term, from left to right.

group of first user/early adopters. This would provide a formal way for feedback and accelerated product development opportunities by understanding of the limitations of the technology. With this new technology being a novel way of directing animals in the landscape it was thought that early promotion of the values of the product would be needed. This would be done by delivering the knowledge gained in animal behaviour and welfare research associated with the virtual herding to the consumer/community. It was also identified that the data collected by the collar itself may be able to be used to demonstrate the continued well-being of the animal including, and beyond, position of the animal in the environment.

To enable future applications, the virtual herding hardware would need a range of extra sensors to be added, such as temperature logging, and further algorithms to predict, for example, rumination events, may be needed. These would be developed as the use of the technology increased. Greater accuracy of animal control will develop through more precise GPS technology and the potential to link to other data sources such as GIS software. These linkages would enable further refinement of animal control and provide the opportunity to prevent animal access to a range of sensitive parts of the environment beyond waterways. This level of fine control would be the trigger for the creation of opportunities in grazing animals sharing environments with other enterprises such as horticulture and arable.

As the technology is developed towards fine control, the need to engage and develop new skills within the community becomes apparent to capture the potential opportunities. At this level there become new opportunities to engage and employ a wider range of skills, beyond traditional livestock management. This then provides opportunities for the wider farming family to remain engaged. At the same time, it enables the attraction of a wider range of skillsets into a community. This may be physically or virtually. The potential to engage virtually may see significant shifts in the interconnectedness of rural communities with both urban communities and consumers. This may

be an outcome from the deployment of many digital technologies as they become part of farming.

Automation of both data capture and reporting will be an important part of capturing the opportunities. Currently there can be reluctance to share data with others beyond the farm boundary. The development of secure protocols, appropriate data ownership and sovereignty structures and trusted networks will be integral in realising future opportunities. These processes will also be important in developing new business models and value chains.

Outcomes

The development of insight into potential futures as the implementation and development of virtual herding, as an enabling technology resulted in the following list of outcomes.

Social License outcomes

- Virtual herding technologies ensure that cattle are seen to be in the right place.
- Social licence to farm is secured.
- Validation is provided for farm environmental plans/ quality assurance schemes.
- Cattle are proven to be well-fed and healthy.
- A story of care is underpinned using individual animal data.
- A record of compliance with regulation is provided.
- The great environment of farmed animals is demonstrated to consumers.

Environmental outcomes

- High water quality attributes are protected.
- Greenhouse gases and nitrate outputs are reduced.
- Information provided to prove the minimisation of externalities in production.

Business outcomes

- More product is sold due to improve resource-use efficiency.
- Proof of environmental attributes provide extra value to products.
- Biosecurity of cattle is secured through movement control and record of location.
- More diverse enterprises emerge where animals are

matched to landscapes.

- Intensification in the right parts of the environment.

Social and cultural outcomes

- Rural communities are revitalised with new-generation users.
- Archaeological, biological, and sacred sites are protected.
- Maintained or improved Māuri of Whenua and Wai.

Finally, statements reflecting the future state of beef farming, with the implementation of virtual herding were developed, using the four windows of examination.

Productivity: Virtual herding technology will enable precision management of animals and the feed resource, providing new opportunities to tailor individual animal management plans at scale.

Environment: Virtual herding technology will enable precision management of animals and the soil resource, providing new opportunities to direct animals to the right part of the landscape.

Landscape: Virtual herding technology will enable precision management of animals and the biodiversity resource, providing new opportunities to manage the landscape across New Zealand.

Enterprise: Virtual herding technology will enable precision isolation of animals in the landscape, providing new opportunities to diversify enterprises.

Conclusions

In this examination of virtual fencing, we have demonstrated the use of horizontal prototype development to develop the vision of potential pathways from digital technology development that would benefit the sheep and beef industries. The modified four-windows approach provided a useful way of examining the opportunity from different angles, increasing the depth of the investigation. Combining this with the Lead User method generated a robust vision for future innovation. The consensus of workshop participants was that virtual herding, as the example technology, will enable precision management of the landscape, provide proof of activity, allow animals into new landscapes and other enterprises onto livestock land. This enabling technology would need to be supported by development of the people through training, engagement and innovation. Capturing of new opportunities will depend on management and sharing of data, including recognition of sovereignty and development of trusted models. A minimum viable product needs to deliver to user expectations and to add further function before a digital farming future can be realised.

Acknowledgements

The authors wish to thank Agersens, Gallagher, and Pāmu for input and support in this project. We also

thank the farmers and scientists who provided valuable input to the process. Thanks to the MBIE-funded New Zealand Biological Industries in the Digital Age programme and the AgResearch Hill Country Capability programme for funding the work.

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