Final report

Assessing real time tracking technologies to integrate with identification methods and national traceability requirements

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1. Abstract

Tracking and identification technologies are emerging as a practical solution for providing important information for producers and other participants in the red meat supply chain. However, as the number of technology options increase, so does the hype surrounding them and the unrealistic expectations of ubiquitous application. This report presents a comprehensive review of identification and tracking technologies that have relevance for the livestock industries. Focusing on the live animal aspect of the supply chain (from birth to arrival at the abattoir or export centre), this report examines both current and anticipated future technologies that may be of value for integration into the National Livestock Identification System (NLIS) and broader integrity systems in Australia. On-animal sensor systems appear to be the most appropriate for future application, based on the ease of deployment, their established acceptance within the industry (in terms of form factor) and the valuable information they can provide. To illustrate how these technologies may be incorporated into future integrity systems, four approaches, each with increasing complexity, are detailed and discussed, including a critical evaluation of their strengths, weaknesses and technical feasibility. Three case studies were explored including how a future system could aid in the detection and response to a foot and mouth disease outbreak (case study one). Whilst case study two examined how product authenticity claims could be objectively verified and case study three investigated how high standards of animal welfare can be maintained before and during transport. Interviews with key stakeholders were undertaken to explore the potential value producers and the broader red meat industry could obtain through the incorporation of on-animal sensor technology into a future integrity system. Finally, barriers to adoption and the needs of the industry were explored with key stakeholders to guide future research.

2. Executive summary

Background

A key aspect of modern animal production systems is the development of traceability programs. Australia's National Livestock Identification System (NLIS) is considered crucial for biosecurity, food safety and global market advantage. Individual tracking is used for cattle nationally and for sheep in Victoria.

Real-time identification and tracking of animals require a series of technologies or methods to monitor the animal, as well as technologies to scan or check individual identification (ID's) as they move from the paddock to slaughter or export. For a complete end-to-end traceability system to work, there needs to be consideration of two major aspects: animal identification and telemetry (location). Ideally these aspects must be integrated. Research has demonstrated the potential for integration of novel identification and tracking technologies to improve Australia's red meat traceability and integrity systems.

This project has identified technologies that may be applied across multiple species, including both large and small ruminants, and focused on the fundamental technologies that support commercial platforms, rather than the systems themselves. Consideration of the required infrastructure has also been included, which is particularly important for the traceability aspects of the system, where database integration and communication of findings are considered key for adoption.

Objectives

The first objective of this report is to provide a global scan of technologies both within and outside of the livestock industries, that could enable real-time tracking and identification of livestock. Focusing on the live animal aspect of the supply chain (from birth to processor), this report examines both current and anticipated future technologies that may be of value for integration in to the NLIS and broader integrity systems. The second objective is to conduct three cases studies to explore in greater depth how a future integrity system could utilise on-animal sensors in the form of 'smart tag' to add value to the current and future traceability functions (biosecurity, product authenticity claims and animal welfare) to benefit key stakeholders across the red meat supply chain.

Methodology

The project sought to identify on-animal sensor systems most appropriate for future application, based on their established acceptance within the industry and ease of deployment. To illustrate how these technologies may be incorporated into future integrity systems, four approaches, each with increasing complexity, were detailed and discussed. A global scan was conducted to establish foundation knowledge of current and anticipated future technologies that may be suitable for integration with national traceability requirements. Technologies both within and outside of the red meat industry were considered to ensure a broad understanding of the topic. The second and third phases of the review allowed for an independent and thorough evaluation of identified technologies, highlighting their compatibility with current traceability requirements.

An in-depth evaluation of how sensor systems could be applied to key case study functions was undertaken to elucidate any specific issues not brought to light through the literature review process. Industry consultation provided both deeper insights into key issues explored along with a reality check of how the proposed on-animal sensors or 'smart tags' could be applied. Interviews were focused on the integrity functions of the proposed 'smart tag' as opposed to the potential production benefits they could provide.

Results/key findings

This research has demonstrated the potential for integration of novel identification and tracking technologies to improve Australia's red meat traceability and integrity systems. A number of technologies, both within and outside of the livestock industry, were identified. On-animal sensor systems in the form of a 'smart tag' appear to be the most appropriate for future application, based on their established acceptance within the industry and ease of deployment. To illustrate how these technologies may be incorporated into future integrity systems, four approaches, each with increasing complexity, were detailed and discussed, including a critical evaluation of their strengths, weaknesses and technical feasibility. Based on these approaches, a number of example applications were noted, based on both current and perceived future functions of the NLIS.

Stakeholder consultations confirmed that a 'smart tag' has the potential as part of a future integrity system to assist with biosecurity, product authenticity and animal welfare issues. A number of limitations to technology acceptance were also identified.

Conclusions

This research has demonstrated the potential for integration of novel identification and tracking technologies to improve Australia's red meat traceability and integrity systems. A number of technologies, both within and outside of the livestock industry, were identified as having potential value. On-animal sensor systems appear to be the most appropriate for future application, based on their established acceptance within the industry and ease of deployment.

To illustrate how these technologies may be incorporated into future integrity systems, four approaches, each with increasing complexity, were detailed and discussed, including a critical evaluation of their strengths, weaknesses and technical feasibility. Three specific case study applications of on-animal sensors were explored through industry partner interview to evaluate the technical feasibility of the proposed systems delivering on integrity system requirements. In all case studies (FMD detection, PCAS accreditation and transport welfare) the theoretical potential for on-animal sensors was supported.

However, several key issues need to be addressed before a whole-sale (or even partial) transition to an on-animal sensor-based Integrity System should be considered:

- This technology is only now emerging as a commercially available tool and still requires significant technical evaluation and likely refinement.
- Critical to success is the long-term reliability and retention rates of any on-animal sensor system to be used. This will need to match or exceed the performance of current NLIS ear tags. As at the time of reporting, no long-term tests (>3 months) of any emerging on-animal sensor systems have been reported.
- There is little base line economic data to enable an estimate of the potential industry level benefits that an on-animal sensor-based Integrity System might bring. There is a key need for research into the likely benefits and costs that these technologies might bring in terms of biosecurity, product integrity and animal welfare claims as opposed to on-farm benefits.
- Benefits to producers outside the NLIS functionalities could be significant. This is dependent on the complexity of the system implemented and the production system of application. Nevertheless, benefits should be considered as a win-win and leveraged in terms of cost reduction of the NLIS implementation.

- Producer perceptions of the use of data from advanced sensing systems will be critical with adverse reactions to the concept of “big brother” watching their animals resulting in significant push back. Strategies will need to be considered to overcome this risk.

Recommendations

- To inform future investments, an economic analysis of the potential benefits that these systems might bring needs to be undertaken. This economic analysis should focus on the value proposition around specific integrity system functions (both current and future) such as biosecurity, product authenticity and animal welfare claims. This critical information will help both MLA and technology developers prioritise investments.
- An on-animal sensor, preferably in ear tag form factor, with absolute location (GNSS) and activity sensing (accelerometer or similar) will likely be of significant value for future integrity system functionality and the development of these systems should be pursued by the industry concurrent to the continued use of existing NLIS technologies. In an initial phase, this might best be supported by facilitating small scale case study projects. These projects would be based around a key integrity system function and provide technology developers with the opportunity to have their equipment evaluated in this specific context.
- One of the key pieces of information currently not available to the industry is the likely retention rates of sensor ear-tags of varying weights and pin configurations. A long term (>3 years) independent study exploring this simple concept could provide valuable insights for technology companies seeking to develop suitable hardware solutions for a future integrity system.
- While an on-animal sensor appears to be the most viable option other technologies could provide benefits across specific functions of the integrity system. Examples include integrating DNA tracking for post-processing product tracking and satellite based remote sensing of livestock numbers and locations. These could be considered for initial economic evaluation and then where viable considered for case study evaluation.

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3. Introduction

A key aspect of modern animal production systems is the development of traceability programs. The first Australian traceability system was introduced in the 1960s for bovine Brucellosis and Tuberculosis control (Animal Health Australia 2015). Over time, the system developed further, culminating with the development of the current NLIS. First introduced for cattle traceability in 1999, NLIS has since expanded to include sheep, alpacas, pigs and goats (NLIS 2009). Endorsed by Federal and State governments, as well as producer, feedlot, saleyard and processors, NLIS is considered crucial for biosecurity, food safety and global market advantage (NLIS 2019).

The NLIS aims to provide whole-of-life identification; tracking animals from property of birth to slaughter or export (O'Sullivan 2010). Currently, individual or mob-based identification is used at key points in the supply chain (e.g. initial tagging, transport, saleyard and abattoir). Individual tracking is used for cattle nationally and for sheep in Victoria. Mob-based tracking is used for sheep bred in all other states. As digital monitoring technologies continue to develop across many industries, real-time sensor-based identification and tracking of animals has been identified as a potential method of system improvement.

Real-time identification and tracking of animals require a series of technologies or methods to monitor the animal, as well as technologies to scan or check individual identification (ID's) as they move from the paddock to slaughter or export. For a complete end-to-end traceability system to work, there needs to be consideration of two major aspects: animal identification and telemetry. Ideally these aspects must be integrated. Research has demonstrated the potential for integration of novel identification and tracking technologies to improve Australia's red meat traceability and integrity systems. The milestone 1 report identified an on-animal sensor system as the most appropriate for future application, based on their established acceptance within the industry and ease of deployment. To illustrate how these technologies may be incorporated into future integrity systems, four approaches, each with increasing complexity, were detailed and discussed, including a critical evaluation of their strengths, weaknesses and technical feasibility. Based on these approaches, a number of example applications were noted, based on both current and perceived future functions of the National Livestock Identification System (NLIS).

Engagement with key stakeholders is needed to evaluate the potential for a future integrity system for traceability purposes to add value to the current NLIS and be adopted by the industry. The case studies chosen for further exploration reflect key functions within the current or future integrity systems for traceability functions including:

- Biosecurity – notifiable disease
- Food safety – product authenticity claims
- Industry sustainability – animal welfare

4. Objectives

Project objectives included:

1. Global scan for technologies within and outside the livestock industries that will enable real time tracking and identification of livestock covering both current and anticipated future technologies

2. Opportunities to link tracking and identification technologies, including prioritised recommendation for proof of concept studies

3. Recommend use cases and combinations of technologies for trialling across the supply chain based on successful application in other industries, and taking into account risks and other challenges related to adoption in an Australian production environment

4. Provide a comprehensive final report, along with a power point presentation summarising the project findings.

5. Throughout the project collaborate with other project teams as directed by ISC and its designated program coordinator.

4.1 Research context

This review focuses on the live animal aspect of livestock production; from birth to slaughter or export. Ideally, universal development across multiple species would be beneficial. As such, this report has broadly attempted to identify technologies that may be applied across multiple species, including both large and small ruminants. However, given the differences in practical application between cattle and sheep/goat systems, independent discussion of these aspects has also been included where necessary.

This review has focused on the fundamental technologies that support commercial platforms, rather than the systems themselves, although a summary of known commercial systems (both livestock and other industries) is provided in Appendices A and B. Consideration of the required infrastructure has also been included. This is particularly important for the traceability aspects of the system, where database integration and communication of findings are considered key for adoption.

Additionally, this research has undertaken an in-depth case study approach to explore the potential for sensors (e.g. location and attribute tracking) to impact on the key functions of a future integrity system. We have attempted to identify requisite parameters for adoption and the associated risks. This has been conducted with the view of future application of the NLIS, with aspects of industry sustainability and animal welfare expected to become critical in the coming years.

This research focuses on exploring how a Level 1 and 4 System (Table 1) could be applied within a future integrity system with specific reference to three case studies. Case study 1 provides an analysis of how a future integrity system could aid in the detection and response to a foot and mouth disease (FMD) outbreak. Case study 2 explores how product authenticity claims for cattle in the Pasture-fed Cattle Assurance System (PCAS) can be verified. Case study 3 examines how a future integrity system could contribute to ensuring all animals are 'fit-to-load' and welfare is not compromised during their journey.

Consultations were conducted to obtain the opinions of key stakeholders as to how a future integrity system incorporating on-animal sensor technology could improve outcomes for producers and the broader red meat industry. Finally, this research also provides an overview of perceived issues related to the adoption of a future integrity system highlighted through the key stakeholder interviews.

5. Methodology

5.1 Review

A global scan was first conducted to establish foundation knowledge of current and anticipated future technologies that may be suitable for integration with national traceability requirements. Technologies both within and outside of the red meat industry were considered to ensure a broad understanding of the topic. The second and third phases of the review allowed for an independent and thorough evaluation of identified technologies, highlighting their compatibility with current traceability requirements. All aspects were considered, including hardware, software, connectivity and useability. With an array of technologies available or close to being on the market, it is as yet unclear which, if any, will be the optimal end-to-end system for the identification, tracking and traceability of livestock under commercial conditions.

Next the use of on-animal identification and tracking sensor systems was explored to provides a broad overview of potential future opportunities for the NLIS and broader integrity systems. Four approaches (level 1-4), each with increasing complexity were outlined and discussed, including the benefits, challenges and technical feasibility associated with each. It is important to understand how these proposed approaches could be specifically applied and how these sensors might be integrated into future integrity systems. To explore this, a basic description of the various functions of the current NLIS was undertaken (both current and perceived future functions), along with a general review of how new technologies (level 1-4) might be applied to improve this system. Using a case study approach the current traceability functions were considered under two major areas: biosecurity and food safety. Future traceability functions considered include industry sustainability and animal welfare.

5.2 Case Studies

The initial assessment of on-animal sensor capabilities against future functions of the NLIS and broader integrity system provided insights into how identification and traceability technologies might meet the required needs. However, an in-depth evaluation of how sensor systems could be applied to key case study functions was undertaken to elucidate any specific issues not brought to light through the literature review process. This in-depth industry consultation provided both deeper insights into key issues explored along with a reality check of how the proposed on-animal sensors or 'smart tags' could be applied. The scope of these case studies was necessarily limited as exploring all potential levels of technology development and future traceability needs would be excessive. Interviews were focused on the integrity functions of the proposed 'smart tag' as opposed to the potential production benefits they could provide.

Fifteen key stakeholders within the red meat industry were recruited to participate in a Zoom interview with the research team. Participants consisted of producers, government officials tasked with biosecurity, employees of auditing bodies, truck drivers and representatives of livestock transport companies. Some participants provided their opinion on one case study, others on multiple activities depending on their area of expertise.

The interview involved an explanation of the on-animal sensor technology in the form of a 'smart tag', and what a future integrity system for traceability purposes could comprise of. Next, the key activities for each case study topic were outlined (using diagrams to assist) and each participant asked if they could see any value for a producer or the broader red meat industry from the application of a 'smart tag.' Participants were also asked to identify any potential barriers to adoption they perceived and what capacity building activities were required for stakeholders to be confident in using the information derived from a ‘smart tag.’

Each interview was recorded and transcribed. Thematic analysis was undertaken to develop a narrative to describe the experiences of participants with the current integrity system for traceability purposes and to obtain their perception of the value the incorporation of on animal-sensor technology could bring in the future. Thematic analysis was undertaken to determine the key barriers to adoption of a future integrity system that were identified by participants.

The CQUniversity Australia Human Research Ethics Committee approved this research: application ID 22601.

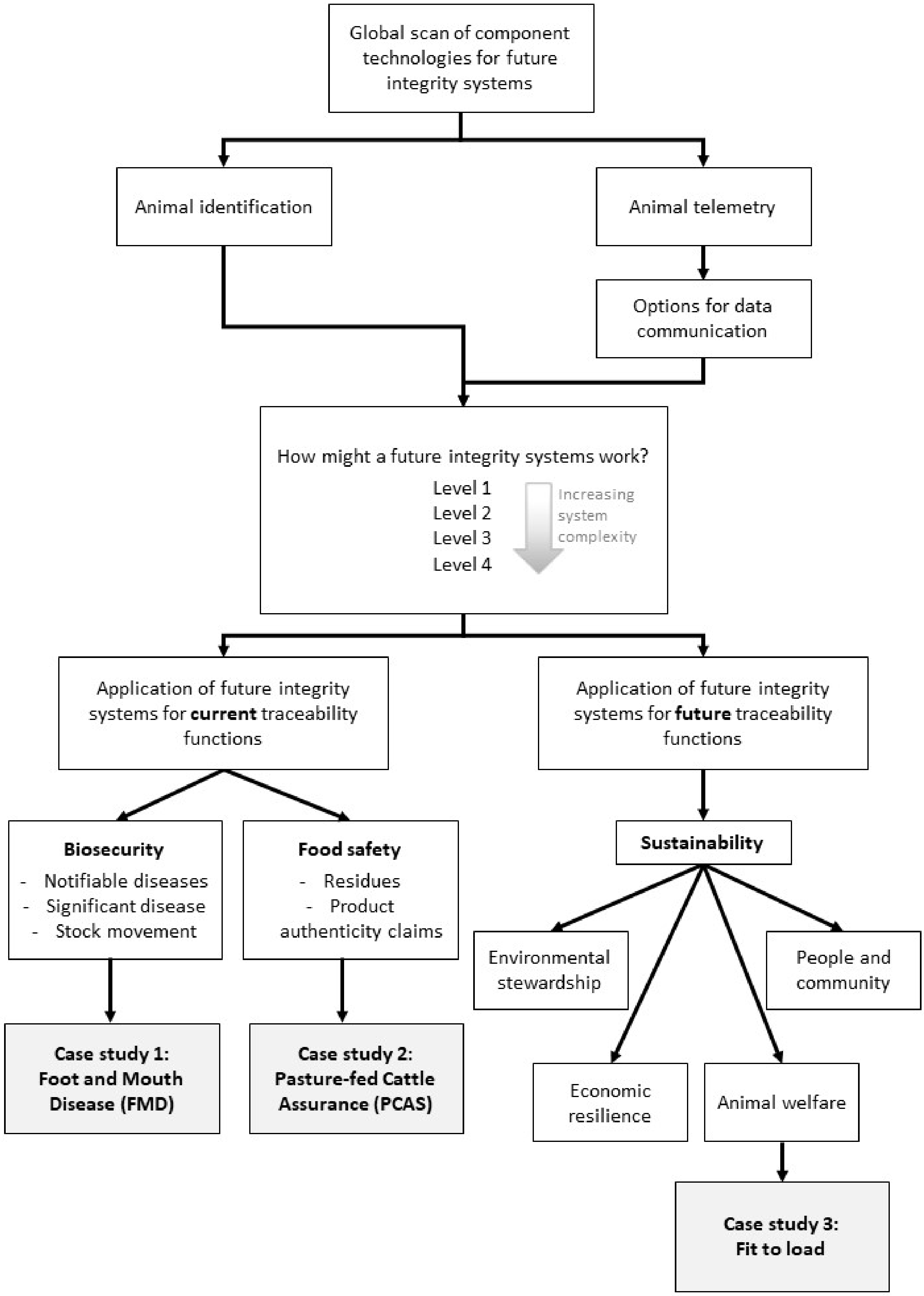
6. Brief overview of report structure

The structure of this report is presented as per the following sections:

1) Global scan for technologies within and outside the livestock industries that will enable identification and tracking of livestock;
2) Discussion of the scope for future integrity system structure including a critical evaluation of how technology could be integrated and potential future opportunities. These opportunities are based on a scaled-up approach presenting options from least-to-most complex; and
3) Application of the identified opportunities for current and future traceability functions. Current functions are considered from a biosecurity and food safety viewpoint. Future traceability is focused on industry sustainability.
4) In-depth industry consultation was undertaken to develop three case studies which provided insights into how the proposed on-animal sensor systems could be applied to current (biosecurity and food safety) and future (industry sustainability) integrity system functions.
5) Recommendations, firstly those relating to the further development of this project; and secondly, those more general in nature that can be taken forward independently of current project outcomes are outlined.

For contextual purposes, a visual schematic of the report is presented in Figure 1.

Figure 1 Schematic outline of the report structure



7. Review of component technologies of future NLIS platforms

7.1 Identification

Identification of animals has traditionally been conducted using individual animal-based methods; for example, ear notching, tattooing, branding, visual ear tags and Radio Frequency Identification (RFID) (Awad 2016). These methods can be permanent (notching, tattooing, branding) or temporary (visual tags, RFID). Regardless of the identification method, the overall aim of each is to ensure accurate identification of individual animals and/or similar cohorts. For the majority of identification methods, the producer must manually observe and record the identification number (Trevarthen 2007). The exception to this are RFID devices, which are read by electronic scanners.

In more recent years, biometric identification of individual animals has been identified as a promising method, particularly for cattle (Awad 2016). This refers to the use of certain biometric features which are unique to each individual, even between animals of the same species (Li et al. 2017). Biometric features of interest include coat colours, muzzle patterns, body imaging and DNA testing.

The following sections explores each identification method in detail. Although traditional methods of identification do not represent 'novel' technologies, they have still been included to ensure a holistic evaluation and may in some way form a component of a more advanced solution going forward.

Permanent identification – ear notching, tattooing and branding
Permanent methods of identification include methods of ear notching, tattooing or branding. These methods cause permanent alteration of some part of the animal's tissue (Awad 2016), with a combination of unique symbols, letters, numbers or shapes allowing identification of animals either at a cohort level (e.g. three symbol brand used in Queensland to identify owner/originator) or individual animals (e.g. shoulder number brands used by some breed societies). In general, permanent identification methods are very affordable and have moderate to high success of reading (Awad 2016). However, these methods are invasive (Kumar and Kumar Singh 2017), essentially resulting in animal defects (Noviyanto and Arymurthy 2013), and are known causes of pain and distress (Awad 2016). Moreover, these methods can be easily duplicated or forged, resulting in fraudulent identification of the animal (Kumar and Kumar Singh 2017). These systems of identification remain difficult to automate in terms of developing image analysis techniques that can recognise the brands or tattoos automatically and deliver digital information into the supply chains.

Visual ear tags
Where producers seek to identify individual animals for management purposes, visual ear tags remain one of the most readily used techniques. At a minimum, these tags contain unique identification alphanumeric code to identify the animal or flock and a Property Identification Code (PIC). If space permits, additional information may also be included, such as vaccination status. Finally, the colour of the tag may be used to indicate some particular feature of that animal or cohort such as the animal's year of birth (National Livestock Identification System 2017).
Visual ear tags are generally considered easy to read, affordable and convenient to use for on-farm management purposes (Awad 2016). However, there are also limitations associated with their use. In a study of the welfare implications of ear tag use in cattle (Johnston and Edwards 1996), metal ear tags were found to cause a moderate to significant level of damage in 29% of animals, including visible changes to the ear's integrity. This has obvious concerns for the animal's overall welfare. In the same study, polyurethane tags resulted in considerably less damage, with 16% of cattle displaying only a slight reaction. This highlights the requirements for proper tag design before use. Other limitations of visual tags include the loss of tags, corruption of the tag with long term use (Andrew et al. 2017) and

the pain associated with application (Kumar and Kumar Singh 2017). Again, similar to permanent methods of identification, visual ear tags may also be duplicated and forged (Awad 2016).

In general, visual ear tags are usually stamped with an identification number which can be manually read and recorded. As computer vision continues to develop, there is the possibility that automated text recognition technologies could be used to automatically identify animals. This could also be achieved through barcode or QR code recognition if printed on the tags themselves. This is already used in supply chain companies (ABBYY 2020), where logistics automation is common. Machine vision has also been explored for automated visual ear tag identification in beef cattle (Velez et al. 2013), although issues associated with dirty tags and poor illumination were noted.

Radio Frequency Identification (RFID)
RFID of animals has become increasingly common in livestock systems. RFID systems encompass three main components: the RFID tag, the reader and a computer-based database or information management software (Ruiz-Garcia et al. 2009). RFID tags can be passive or active.

Passive RFID tags do not have an internal power source. Instead, they receiver power by the electromagnetic energy transmitted from a RFID reader located in close proximity and use this energy to energise the antenna and transmit back a unique identifier (Trevarthen 2007). Due to the absence of a power supply, passive tags are unable to transmit any radio signal or data in real-time (van der Sluis et al. 2018) and are more commonly used for point of interest identification-only purposes. They also have a shorter read range and cannot store information (Trevarthen 2007).

Active RFID tags contain a battery source, enabling them to initiate communication with a RFID reader (van der Sluis et al. 2018). Consequently, active tags are commonly heavier than their passive counterparts. However, their key benefit is that they are able to broadcast their identity and can consequently transmit at further distances to the reader.

Within the active RFID group, there are two different types of tags, namely beacons and transponders.

- Beacons do not wait to 'hear' a signal from the reader. Rather they transmit (also known as 'beacon') specific information (for example every 3 – 5 seconds). The major advantage of this tag is that they can transmit over hundreds of metres. However, their transmit power is lower in order to conserve battery life.
- Transponders wait for a signal to be sent from the reader. Once this signal is received, transponders send back a signal to the reader with the relevant information. These tags are very efficient because they conserve battery life when the tag is out of range of the reader.

In contrast to permanent identification methods and visual ear tags, RFID does not require line of sight for either human initiated or automated visual recognition (Trevarthen 2007). This is reported to result in reduced operator error and labour costs (Eradus and Jansen 1999). In addition, RFID makes it easier for multiple animals to be identified within a short period of time (van der Sluis et al. 2018).

RFID technology can be used in different frequencies: Low Frequency (LF), High Frequency (HF), Ultra-High Frequency (UHF) and Microwave (MW) (Table 1). Frequency impacts the read distance and penetrative ability of the signal. Passive RFID can operate at a number of frequencies, primarily LF, HF and UHF. Active RFID generally operate at higher frequencies, including UHF and MW (Trevarthen 2007).

Table 1. RFID operating frequencies. Adapted from Trevarthen (2007) & Bowler (2014)

Frequency band	Typical frequency	Read distance	Read distance	Interference from water & metal	Typical use
Low Frequency (LF)	125 – 134 kHz	< 0.5 m	Shorter	Lower	Animal ID, car immobilisation/security
High Frequency (HF)	13.6 MHz	1 – 1.5 m			Access control, contactless payments
Ultra-High Frequency (UHF)	433 MHz or 862 – 915 MHz	3 – 10 m[1]			Baggage tracking, supply chain logistics
Microwave (MW)	2.5 & 5.8 GHz	Up to 10 m	Longer	Higher	Electronic tolls, item tracking

[1] Read distance is frequency dependent. Frequencies of 433 MHz can have read distances of up to 100 m (Bowler 2014)

Low Frequency RFID

LF RFID can penetrate most materials without absorption. However, communication range is limited. In general, LF RFID is considered the most efficient technology for identification of animals as it is able to penetrate through living tissue (Hogewerf 2011). There are three main form factors of LF RFID commonly used in livestock systems, these are discussed in detail below.

Ear tags

RFID ear tags are attached to the animal's ear and scanned by a RFID reader as required. Ear tag RFID are usually passive devices. Similar to visual tags, physical loss or damage to the tag is considered a critical issue for adoption (Xinova 2019). In an MLA funded study of a beef operation of Northern Queensland (McKellar 2011), tag retention was found to be high (99%) over a three-year period. However, there was an increased number of tag losses (6%) in one particular cohort, which was found to be the result of manufacturing errors. In another MLA funded report, total tag replacement costs were estimated at $9.9 million per year, with target loss rates of below 2% required to minimise this issue (Xinova 2019). Other issues associated with ear tag usage include the damage following attachment and wound healing process, potentially resulting in inflammation, irritation and swelling (Caja et al. 2014).

Rumen bolus

Rumen boluses are an alternative method of passive RFID. An applicator is used to place these devices into the rumen of the animal and provide a safe and tamper-proof method of electronic identification (Fallon 2001). The key advantage of the rumen bolus is that it cannot be easily removed or lost (Gaunt 2007) and subsequently the retention rate is high (Gaunt 2007; Caja et al. 2014). However, due to the device residing inside the body of the animal, reading of the bolus may be more difficult and time-consuming when compared to reading ear tags with a hand-held reader. This may be more of an issue for large, mature cattle, where the distance from the reader may limit activation of passive RFID (Fallon 2001). Comparatively, electronic boluses are able to be reliably read in sheep using the appropriate equipment (Gaunt 2007). Readability of rumen boluses in goats is also consistent (see Caja et al. (2014) for a review), although lower than that reported for cattle and sheep.

One major limitation of rumen boluses are issues associated with recovery of the device at slaughter and the risk of damage to processing equipment and entry to the food chain (Fallon 2001). Where the rumen is intended for consumption (tripe), this risk is minimal (Gaunt 2007). However, if the rumen is to be processed by rendering equipment, the device needs to be manually retrieved to prevent damaging the equipment. The risk is primarily associated with the devices being ceramic and therefore non-magnetic, meaning there is no current method of easily identifying and removing the bolus prior to rendering.

Implantable transponders

Implantable RFID are another possible method of identification. This RFID technology is generally enclosed in glass and injected under the animal's skin. Similar to rumen boluses, implantable RFID is considered a secure and reliable method of identification (Awad 2016), with lower risks of tampering.

The most appropriate site of injection is not yet agreed upon in the literature. In cattle, injection sites at the ear, forehead, nose, shoulder, behind the foreleg (armpit), kneefold and tail have been studied (see Klindtworth et al. (1999) for a review). Overall, Klindtworth et al. (1999) reported that injection into the scutulum cartilage of the ear or at the back of the ear were most appropriate, though the latter resulted in higher levels of device breakage. In sheep and goats, injection sites at the ear base, neck, chest, armpit, groin and tail have also been explored (Caja et al. 1998). In sheep, the armpit has been found an appropriate injection site (Caja et al. 1998). Similar results have been found in goats (Caja et al. 2014), with increased readability at the armpit and groin.

One significant issue associated with implantable RFID is the migration of the devices from the site of implantation. Not only does device migration increase the risk to the animal's essential organs, but it also raises issues for device recovery at slaughter (Klindtworth et al. 1999). In cattle, injection at the scutulum site has been associated with reduced migration (up to 6cm from the injection site) while still maintaining readability (Klindtworth et al. 1999). Moreover, in another study of injection location in veal calves (Lambooij et al. 1999), recovery of ear-based devices after slaughter was relatively rapid and successful, though issues with readability were found at fattening. In sheep and goats, device migration is lowest following injection into the ear base or tail (Caja et al. 1998; Caja et al. 2014). However, these sites also result in increased loss and breakage and are therefore unsuitable. Comparatively, injection behind the foreleg (armpit) has been associated with moderate migration in sheep and goats, while still maintaining high retention rates and readability. However, this injection site is still associated with issues of recovery at slaughter. Food safety risks of implantable RFID have been raised as a result of device migration and should not be ignored.

High Frequency and Ultra High Frequency RFID

As previously identified, most existing RFID systems utilise LF passive technology. However, these can only be read at a short-range. In contrast, HF and UHF can achieve read distances between 1 and 3m (Table 1), meaning there can be increased distance between the animal and the reader. This can be beneficial in systems where the ability to place the reader in close proximity to the animal is limited, e.g. in yard systems that do not allow close contact between the animal and the reader.
LF systems are also considered unsuitable for identification of several animals at once, a limitation which can theoretically be overcome by the higher data transfer rate of HF and UHF (Hogewerf 2011; Hammer et al. 2016). This capacity for simultaneous detection was examined in a New Zealand study of UHF ear tags in sheep and cattle (Cooke et al. 2010). In this study, when sheep were moved as a

mob through a 2.2m wide race, the readability of tags was 94 – 100%. In cattle, readability dropped to 72% using a 2.6m wide race, although this was attributed to the poor placement of the antenna. In another study of cattle, average reading rates of UHF ear tags were over 86%, with increased accuracy when scanned indoors compared to outdoors (Hammer et al. 2016). Given that most animals in extensive Australian systems are managed in outdoor environments, the suitability of this technology is questionable if it is being used for the purposes of multiple animal identification. If instead the animals are presented in a single file in a narrower race (1m for sheep; 1.2m for cattle), readability is reported at 100% for both species, suggesting feasibility if the animals are managed in this way.

One limitation of HF and UHF is the lower penetrative ability and tendency for water and metal interference (Hammer et al. 2016). For this reason, HF and UHF are more suited for neck collar or ear tag form factors (Hogewerf 2011) rather than a bolus or implantable device. In general, collar-attached devices are common in the dairy industry. However, a collar is not considered realistic in extensive red meat systems, particularly when considering the physical growth of animals between periodic inspections (Hammer et al. 2016). HF and UHF are not suitable for use in an implantable form factor due to the high potential for water absorption and the inability to read the signal through the animal (Hammer et al. 2016).

Bluetooth

Bluetooth is a form of wireless technology that utilises UHF radio. Bluetooth allows communication between two compatible devices, for example smartphones and laptops. This differs from traditional RFID systems, where communication is between the tag and the reader. Bluetooth technology exists in two forms: traditional Bluetooth and Bluetooth Low Energy (BLE). Both versions maintain a similar range for communication, though BLE consumes less energy and is cheaper to maintain. Bluetooth can be used on-farm to connect to the RFID reader, allowing transfer of animal identification from the RFID reader to another device (e.g. smartphone, storage device) (Pretty and Moroz 2013). This data can then be viewed or edited by the producer on the connected device. In this way, the Bluetooth technology is not being used for identification of the animal *per se,* but rather to facilitate the overall flow of information in an on-farm system.

Bluetooth identification technologies also exist, for example the HerdDogg system which utilises Bluetooth to enable transmission of identification, biometric and proximity-based behaviours to strategically placed base stations (Meat & Livestock Australia 2018; HerdDogg 2019).

Near-Field Communication (NFC)

NFC is another type of RFID commonly used in some mobile devices (e.g. Apple and Android smartphones). Utilising passive HF technology, NFC can be used to facilitate contactless payment or ticketing. NFC can also be used for building access control. NFC operates at 13.6 MHz, and transfers information over short distances (less than 10cm). One benefit of NFC over traditional Bluetooth is that the former can function without batteries (Cao et al. 2019) and instead utilise the radio waves generated by the NFC reader for data transmission (Pigini and Conti 2017). This is similar to LF RFID. Although not commonly used in livestock situations, NFC is now being used along the supply chain in other industries; for example, Johnnie Walker Blue Label have incorporated NFC for identification and tracking of individual bottles along the supply chain (Sutija 2015). NFC has also been proposed as a method of ensuring complete supply chain traceability for European pork products (Pigini and Conti 2017).

Biometric identification

Biometric identification of animals relies on methods of identifying biological characteristics that are largely unique to individuals (Li et al. 2017). In a review of cattle identification methods (Awad 2016), the author's identified four requirements of biometric features: (i) universality; (ii) uniqueness; (iii)

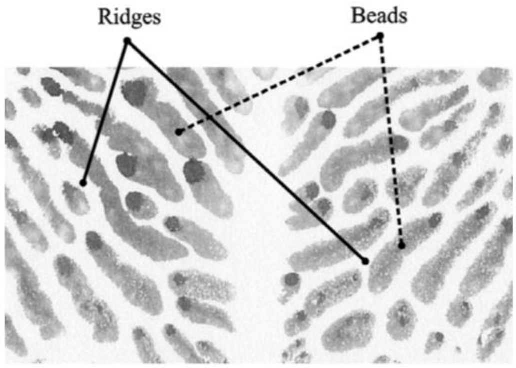
performance; and (iv) circumvention. *Universality* requires the feature to be available for every individual. Each feature must also be *unique* to the individual. Adequate *performance* for identification (accuracy and speed of detection) is also essential. Finally, *circumvention* relates to the robustness of the system, or how easily it can be affected by fraudulent information.
Most often biometric identification relies on some method of image-based pattern recognition. This is usually conducted by the use of specialised imaging or camera equipment. In livestock research, various methods of biometric identification have been explored. However, application in commercial situations is not yet widely adopted. Commonly explored biometric identification methods are discussed in detail in the following sections.

Coat patterns
The majority of image-based identification research has been conducted in multi-coloured cattle breeds (e.g. Holstein-Friesian), where distinctive coat patterns can be more easily identified. For example, Andrew et al. (2017) successfully utilised computer vision technology to identify Holstein-Friesian cattle based on their unique dorsal pattern. In another study, Li et al. (2017) utilised similar computer-based recognition, to identify animals based on their tail head coat pattern. While this research supports the use of image-based identification, the technology largely relies on the presence of unique coat patterns, an aspect that are less common among beef cattle and sheep breeds. It could be feasible to impose a unique coat pattern colour change through freeze branding. However, the practical implementation of this at both the farm level and at a national scale would be difficult.

Muzzle print identification
Muzzle patterns are considered a robust method of identifying individual animals. Similar to fingerprint identification, muzzle prints are unique among individuals, even those of the same breed (Awad 2016). Much of the research to date has focused on cattle muzzle identification, with very little investigation on sheep or goats.

Cattle muzzle identification relies on the detection of two objects: beads and ridges (Noviyanto and Arymurthy 2013). Beads refer to the raised section of the muzzle, while ridges form the “rivers” that separate them (Figure 2). Methods for muzzle print identification rely largely on pattern recognition and computer vision analysis (see Kumar et al. (2018) for a review). Though methods of analysis differ, muzzle print identification requires the collection of quality muzzle prints from the animal. This can be done by ink and paper (Noviyanto and Arymurthy 2013) or camera (Kumar et al. 2018). In general, muzzle print identification of cattle has a high level of accuracy (Noviyanto and Arymurthy 2013; Kumar and Kumar Singh 2017; Kumar et al. 2018). However, issues associated with print collection are noted, including smeared prints or poor-quality images (Awad 2016). Of interest, Kumar et al. (2017) was able to identify individuals in real-time from muzzle images captured using surveillance cameras, although the study was more of a theoretical application of the proposed system, rather than *in-situ*. This process yielded a 96.9% accuracy and 10.3s recognition time. This has implications for the red meat industry, particularly those in more intensive feedlot environments, where application of surveillance cameras for individual identification may be possible.

Figure 2. Muzzle print showing beads and ridges. Source: (Noviyanto and Arymurthy 2013)



Research regarding muzzle print identification of sheep and goats has received less attention in the literature. A single publication was found detailing the ability of untrained operators to match images of beef and sheep muzzle prints based on visual sight alone (Rusk et al. 2006). In this study, 38 adult volunteers were asked to determine if 20 pairs of muzzle prints (equal split of cattle and sheep) were a match through visual observation. Retinal images were also used in this study, and the results are discussed in the following section. The participants were given sample image sets in random order and asked to determine which pairs of images were a match. The overall accuracy of the visual verification exercise was 68.9% and 79.5% for beef and sheep, respectively. Based on this, although the authors conclude that collection of muzzle prints could be reliability used for visual identification, the overall performance does not support its use on a large scale, particularly considering the likely difficulty in collecting muzzle prints in large extensive red meat systems.

Retina-based identification

Retinal identification relies on the pattern of vascularity in the animal's eye, a highly unique and distinct trait of both humans and livestock (Gonzales Barron et al. 2008). In the previously identified study of beef and sheep muzzle identification, Rusk et al. (2006) also presented the untrained volunteers with 20 retinal images (equal split of cattle and sheep) and asked them to determine if image pairs matched on the basis of visual appearance alone. Overall, the operators were able to match images with an accuracy of 98.6% and 84.9% for beef and sheep, respectively, including a false match rate of 0.5% and 27.6% (Rusk et al. 2006). Similar to the muzzle prints, the authors concluded that retinal images were a reliable method of identification, although issues associated with the cost of equipment were noted as drawbacks. Furthermore, in the application by Rusk et al. (2006), the purpose of the study was to determine if the volunteers could identify matching prints with the aim of using this method for identification of animals in agricultural shows. Thus, the validity of these results has somewhat limited application for traceability purposes, given that identification of prints by visual observation alone would be unlikely in large scale traceability systems.

In another study of sheep, matching of retinal images using proprietary software demonstrated a high level of recognition (0.25% of false matches). In this case, neither light conditions (indoors vs. outdoors with shade) or individual operator had a significant effect of matching accuracy (Gonzales Barron et al. 2008). Again, although this study broadly highlights the potential for use of this technology for identification purposes, the two studies were conducted on relatively small numbers of animals, without necessary consideration of how this would be applied for commercial identification in large scale red meat systems.

Further to the above, retina-based methods also have a number of limitations which may limit their commercial viability. Chiefly, retinal images must be collected with expensive specialised equipment and collection time may be longer than other identification methods (Rusk et al. 2006; Gonzales Barron et al. 2008). This will limit the adoption of this technology more broadly across the red meat industry, particularly in extensive situations with large numbers of animals across a vast landscape. In addition, sufficient training is required for consistent use of the technology, with Gonzales Barron et al. (2008) recommending at least 15h per operator. Again, this may limit the uptake of the technology.

Iris patterns

Similar to retina-based identification, iris patterns can be used for animal identification purposes. In a study of cattle iris recognition (Sun et al. 2013), the proposed methodology was found effective at capturing and recognising iris data. This was considered particularly important as the proposed method was unaffected by image rotation or scale. In another study of cattle (Lu et al. 2014), iris recognition was accurate in 98.3% of cases. While these results were positive, in both cases only a small number of animals were tested [n = 18 (Sun et al. 2013) and n = 3 Lu et al. (2014)], and thus further research is recommended. Changing iris appearance due to age, disease or medication has also been reported (Awad 2016), meaning that this method of identification may not be appropriate for lifetime identification. Furthermore, as livestock are largely a considered 'noncooperative' species (Sun et al. 2013), collection of clear images is often difficult due to occlusion by eyelids or eyelashes.

Facial recognition

Facial recognition is considered to be the most commonly applied biometric characteristic used in human identification (Cai and Li 2013). In recent years, the use of the technology for identification of livestock has also received attention. In cattle, experimental results of 3,000 facial images found recognition of individuals was possible (accuracy 74.4% - 87.0%) (Kumar et al. 2016). A similar result was also reported by Cai and Li (2013), with recognition accuracy between 67.6% - 95.3%. In contrast to identification using distinctive coat patterns, facial recognition does not require unique markings for identification. Instead, this approach focuses on textural features or 3D visual appearance (Andrew et al. 2017). This was shown in a study by Kim et al. (2005), where the faces of 12 Japanese black cattle were able to be adequately identified using changes in grey-scale image brightness, distortion and input noise. Facial recognition has also been reported for sheep (accuracy 95.3 – 96.0%) (Corkery et al. 2007).

Similar to collection of muzzle prints, facial recognition may be impacted by different backgrounds, light sources or animal poses (Kumar et al. 2016). This is a particular concern when images are collected in an outdoor environment, where weather and lighting are unpredictable. To circumvent this, the images must be aligned and cropped to contain only the relevant information (Cai and Li 2013). Overall, facial recognition technology is considered a non-invasive and cost-effective method of identifying livestock when background conditions are favourable. However, the issues with its current accuracy mean its application within a national traceability scheme are limited where accuracy requirements exceed its current abilities.

DNA testing

DNA testing refers to a branch of identification technologies that utilise genetic material to identify individuals. The technologies have developed over the years, from early stage DNA profiling to recent developments of single nucleotide polymorphisms (SNPs) (see Cunningham and Meghen (2001) for a review). DNA profiling of livestock has been examined for a number of species, including cattle (Trommelen et al. 1993), sheep (Crawford and Buchanan 1990), goats (Jimenez-Gamero et al. 2006), and pigs (Fortune 2020), for the purposes of identity testing (cattle), parentage testing (cattle, sheep, goats), pedigree testing (sheep) and DNA traceback (pigs).

For identification purposes, application of DNA technologies could be achieved in four main ways. These have been explained in detail by Cunningham and Meghen (2001), and have been briefly reproduced in Table 2.

Table 2 Application of DNA identification technologies. Adapted from Cunningham and Meghen (2001)

Application	Description
1. Identification through comparison with a known living relative	This approach requires no specific infrastructure for sampling and archiving. However, it is limited if no living relative exists.
2. Identification by comparison with a sample previously taken from the same animals	Available samples are often taken for purposes of disease screening. This approach is more powerful than comparative parental analysis. However, it requires adequate infrastructure for archiving of samples.
3. Systematic sampling of young animals and archiving of samples	This approach requires samples (including hair or tissue) to be taken from all animals at first tagging for subsequent archival. Sufficient infrastructure is required for storage of samples.
4. Systematic sampling and DNA profiling of animals	An extension to the above. The samples are taken, processed and stored on a centralised DNA database. This has an additional benefit of allowing identification of unmarked animals. Issues associated with cost of implementation would need to be considered.

DNA testing introduces a novel method of identification using permanent and immutable methods. However, limitations of DNA testing include the cost and time of sampling and processing which make it impractical on a large scale (Stanford and McAllister 2001). Furthermore, DNA sampling is usually conducted through collection of blood, hair or semen, and thus represents a significant barrier for adoption in extensive systems. Whilst not entirely overcoming all limitations, new sampling methods which integrate tissues testing into other management practices could provide valuable additions to a traceability program. For example, the Allflex® tissue sampling tags which allow for collection of tissue during ear tag application (Allflex 2019) could be integrated with a NLIS ear tag system. However, this technology is still in its commercial infancy and is not yet offered in Australia. Nevertheless, DNA testing has been introduced in other market sectors, for example, fork-to-farm traceback for Dutch pork products (Fortune 2020). It is worth noting that tissue sampling and DNA more specifically provides one of the few key opportunities for tracing the animal and final product all the way from pre-farm gate through to consumer.

Novel identification technologies

In addition to the above technologies, there are potential novel identification systems that should be noted. Hair whorls refer to growth of hair in the opposite direction from the hair surrounding it (e.g. in a swirl shape or tufted hair). Facial whorl positions have been attributed to temperament in species including cattle and horses. For example, cattle with facial whorls located higher on the face were found to have higher levels of agitation in the auction ring (Lanier et al. 2001). Hair whorl patterns have also been associated with productivity traits, including time to puberty and total milk yield (Young et al. 2007). Hair whorls are generally unique among individuals, and thus can be used for identification of horses (Yokomori et al. 2019), including in registration of animals by breed societies (Australian Stock Horse 2020). However, their use for individual identification of cattle has not yet been established. The feasibility of using this method for traceability purposes is also unlikely given that a natural proportion of the cattle population do not have facial hair whorls (Lanier et al. 2001).

Another novel technology that has been explored for identification of animals is near-infrared reflectance (NIR) spectroscopy. NIR spectroscopy has been used for the identification of different foods, beverages and animal products, however its use for analysis of animal hair samples is less common. In a study by O'Neill et al. (2017), tail hair samples were used to distinguish between cows and calves of the same breed (Brahman). The samples were scanned using a fibre optic probe operating in the NIR region. Overall, NIR spectroscopy was able to correctly identify 92% of cow samples and 100% of calf samples. The findings also supported the identification of animals based on sex. Overall, although the study was unable to identify specific individual animals, the practical implications of being able to identify animals of different classes should not be immediately dismissed. Though not a suitable technology for immediate application, NIR spectroscopy could with further research be a technology for use in the future.

7.2 Animal telemetry

As detailed above, various technologies can be employed for animal identification purposes. However, application of these technologies for the purpose of identification alone undersells their value, both in terms of farm profitability (Eradus and Jansen 1999) and more widely as a benefit to industry through traceability. Instead of simply considering the ‘who’ (i.e. animal ID), integration of technologies can be used to provide further information on the animal itself, including the location of the animal (i.e. ‘where’ the animal is and/or has previously been) and the corresponding behaviour and/or health-related attributes (i.e. ‘what’ the animal is/was previously doing). It is this ability to connect each individual to their various attributes or metrics (e.g. weight, activity, health status), where significant benefit could lie. The following section explores potential sensing technologies which can be integrated with traditional identification methodologies. Again, the focus has remained on practical application for the red meat industry, particularly within the live animal component of birth to slaughter.

Location tracking (where is the animal?)

Location-based technologies provide information on where the animal is located within their environment. These locations can be considered absolute (i.e. specific geographic coordinates) or relative (i.e. in relation to another animal or known reference point). In addition to providing location information, a number of these technologies can be further applied to provide information on the animal state, including their behaviour and other attributes. This current section is intended to focus on the location-based capabilities. Further discussion of extended applications is provided in the following section (Section 0 Attribute Tracking).

Global Navigation Satellite System (GNSS)

Tracking of animals using satellite-based technologies has been conducted since the 1980s. First used for wildlife research, GNSS has now become a common system for livestock research (see Swain et al. (2011) for a review). GNSS is considered the umbrella term for all global satellite positioning systems, including the well-known Global Positioning System (GPS) which specifically refers to the NAVSTAR constellation of satellites managed by the United States Department of Defence. GNSS tracking relies on the triangulation of signals from satellites to determine the absolute location of the GNSS receiver on the earth’s surface. As the technology has improved, location estimates can now be achieved within 0.2m using differentially corrected GNSS (Ganskopp and Johnson 2007). GNSS can be used to provide an accurate reconstruction of an animal's movement path and help to determine their interaction with the environment.

Table 3 outlines example applications of GNSS data where the location of the animal has been used to examine their interaction with the surrounding environment.

Table 3. Example applications of GNSS for monitoring of livestock-environment interactions

Species	Research focus	Reference
Cattle	Adaptation between production systems	Thomas and Revell (2011)
	Management on travelling stock routes	Trotter et al. (2018)
Cattle/ Sheep	Grazing site selection	Putfarken et al. (2008)
Sheep	Shelter	Taylor et al. (2011)
	Weather	Thomas et al. (2008)
	Nutrient distribution	Betteridge et al. (2010)
Sheep/ Goats	Co-grazing with livestock guardian dogs	Gipson et al. (2012)
Goats	Feeding behaviour	Goetsch et al. (2010)

In reviews of GNSS technology in livestock settings, disadvantages associated with battery life constraints are often cited (Swain et al. 2011; Bailey et al. 2018). Consequently, appropriate form factors for commercial use (e.g. ear tags) are still in development due to this requirement for sufficient power supply. Other issues are also noted, including hardware longevity and connectivity issues (e.g. data transfer off the device). In a research environment, these limitations are often circumvented by use of a larger "store-on-board" devices, where the location estimates are stored on the device for later download and analysis (Trotter 2010). By using these devices, researchers are able to attach a larger battery unit to the device, which are then often attached to the animal via a neck collar. When considering practical application in a commercial setting, an ear tag form factor is considered most appropriate, as it aligns with conventional husbandry practice for ear tag identification (Barwick et al. 2018b). This is being addressed by numerous commercial companies; for example Ceres Tag (Ceres Tag 2019), Allflex (Allflex 2018), Smart Paddock (Smart Paddock 2020), IDS G Farm (IDS G Farm 2020).

Radio-based location systems

While GNSS provides global location data, similar location data can be gathered using a local radio network. Radio location can be achieved either at a simple proximity level (by nearness of an emitting tag to a reader) or by more complex trilateration techniques.

Passive RFID allows for limited location tracking through transmission of the animal ID as they come into contact with a reader. Active RFID can also be used for more detailed location of animals. Many active RFID emit their own ID at fixed time intervals (beacon RFID). This is then received by the reader which will subsequently recognise and record the ID. Since the tags have their own energy source (i.e. battery) they do not require close contact with readers to initiate communication, and thus their read distance is longer than passive tags (Zhao 2010).

For localisation using active RFID, two major approaches are taken: range-based and range-free.

- Range-based methods use information on the distance or angle between the tag and the reader to estimate the tag location by trilateration. This is most commonly measured by received signal strength (RSS), although other time-based methods (e.g. time of arrival) can also be used (Zhao 2010). For practical application, systematic placement of RFID readers throughout the environment is necessary. From here, the RFID tag (and thus the animal) can be effectively tracked as they move through the environment, coming into contact with various readers along the way.
- Range-free approaches do not have information on distance or angle between nodes, but instead rely on information on the existence of neighbour nodes. One example of this is the LANDMARC system, a RFID system which was initially developed for mobile tracking applications in indoor environments (Ni et al. 2004; Li et al. 2019). Using a system of references tags at known locations throughout the environment, the LANDMARC system compares the signal from these reference tags to the tracking tag to estimate the latter tag's location. Use of the reference tags reduces the requirements for multiple RFID readers, making the system more cost-effective. In addition, as the reference tags are subject to the same environmental conditions as the tracking tags, this helps to offset any environmental factors that may impact signal strength (Zhao 2010).

Ultra-Wide Band (UWB)

While standard HF and UHF technologies are able to provide location estimates, these traditionally analogue technologies were broadly designed for identification purposes only (Dardari et al. 2019). As such, only approximate position information can be obtained (Porto et al. 2014). For higher-accuracy estimates, digital technologies such as UWB can be utilised. In studies of barn-raised dairy cattle, UWB has been reported as providing an accurate method of cow localisation. Porto et al. (2014) reported a maximum location error of 0.8m, concluding that the technology was appropriate for tracking cattle in an indoor environment. In a similar study, Tullo et al. (2016) applied the GEA CowView system (GEA Farm Technologies, Bonen, Germany), noting the technology was at least 93% accurate at detecting the animal's position within the barn (i.e. in the alley, cubicles, trough or at the drinker). In a study of barn-raised sheep (Ren et al. 2020), UWB was found to be highly accurate in determining sheep location in real-time (mean error 0.4 m).

Although these studies broadly support the application of UWB for livestock tracking, the practical application of the technology in outdoor environments has received less attention in the literature. This is mostly due to the inherent characteristics of UWB making it more suitable for indoor use, including that it is not prone to issues with multipath (i.e. bounced signals) and it is able to be used in conjunction with other devices. This is not to say that the technology is unsuitable for outdoor environments. However, focus has mostly been on indoor application in a number of industries. In a study of goat localisation, Georg et al. (2012) applied UWB in a 3500m^2 (0.35ha) outdoor paddock. In this study, the reported location estimates were found to be accurate within 0.15m, highlighting the potential for use of this technology outdoors. Of note, to ensure adequate coverage of the paddock, six readers were deployed, equating to one reader for every 583m^2, or 0.06ha. This has arguably less practical application in extensive red meat systems, where the size of paddocks may be extreme and the number of readers required may be prohibitive.

Bluetooth

Bluetooth technology (as a form of technology that utilises UHF radio waves) also has the capacity to determine the location of livestock. In an experiment by Bloch and Pastell (2020), BLE tags were used to monitor the location of dairy cattle in a barn system. Overall, the tags displayed an accuracy of 3.27m in the barn environment, making them less accurate than UWB systems (Porto et al. 2014; Tullo et al. 2016; Ren et al. 2020).

Radio-based proximity sensing systems
Utilising traditional radio frequency or Bluetooth technology, proximity loggers allow for the frequency and duration of contacts to be recorded when the two devices come within a pre-defined distance of each other through transmission and receipt of UHF signals (including Bluetooth) (Handcock et al. 2009). Devices are usually attached to different animals to study social interactions between species, although they can also be used as static base stations to measure contact with particular reference points within the environment e.g. water points.

Proximity sensing systems have been previously used to study pregnant cattle associations (Swain et al. 2015). In this study, Swain et al. (2015) noted the change in social association in cows, with pregnant and maternal (i.e. previously calved) animals displaying preference for cattle of the same status. This could have production implications by facilitating identification of recently calved animals. Proximity sensors have also been used to study dam-offspring behaviour in sheep (Waterhouse et al. 2019). In this study, there were clear differences in number of contacts between ewes and related or unrelated lambs, with the author's concluding that proximity sensing could be used as a method of identifying specific ewe-lamb relationships. Again, this could have production benefits by enabling enhanced genetic improvement through ewe-offspring matching and collection of valuable information on lamb growth and survival. However, Waterhouse et al. (2019) state that the need and financial benefit of real-time proximity data is less clear, with more case studies needed to better understand this. There is an obvious relationship between the functionality of proximity sensing and traceability in the context that these sensors provide clear evidence for individual animal-animal associations. This data could be of significant benefit in the context of applications across the NLIS and future integrity systems.

Remote sensing and image analysis
Remote sensing and image analysis involves the collection of data corresponding to reflectance values of the electromagnetic spectrum. There are two key components of a remote sensing system; the imaging system (the camera) and the platform to which this system is attached. While the imaging systems are often quite similar in terms of the types of data they capture (visible light, NIR, liDAR and Radar), the platforms vary considerably e.g. satellite collection, traditional airborne platforms, and increasingly unmanned aerial vehicles (UAVs). This variation in platforms has a significant impact on the data resolution (both spatial and temporal) and ultimately impacts on the practical deployment of these in the context of a traceability scheme. This review will explore each platform separately and consider the imaging system with the context of the limitations they pose.

Satellite imagery
Commonly used for tracking of wildlife, collection of satellite images can be used to track animal movement patterns and animal-environment relationships (Tibbetts 2017). This technique can be used to identify an animal itself, or it may be used for indirect surveying of animal occupancy (e.g. faecal counts, burrow counting). In general, satellite imagery has relatively low spatial resolution (1-60m) compared to other methods (e.g. UAVs), although recent improvements in sub-metre resolution are currently emerging (Wang et al. 2019). This may be dependent on the type of imagery collected, with multispectral imagery more useful for distinguishing between the animals and the ground compared to panchromatic imagery. However, multispectral imaging generally has a lower resolution and is therefore more useful for larger species (>2.5m), including whales. Panchromatic imagery has been used with success to detect smaller species, including wildebeests and zebras (Xue et al. 2017).

Given the ability to be deployed over large areas, satellite imagery may be useful in the extensive systems of Northern Australia. Although not able to identify animals at an individual level, application of satellite imagery may be able to monitor stock numbers in a given area. In a review by Wang et al. (2019), automated counts of animals from satellite images were reported as highly correlated to manual counts when applied in small homogenous environments. The accuracy of counts is less accurate in areas of extensive vegetation cover, with the tendency to underestimate the population. Nevertheless, in the more extreme context of Northern Australia production systems, satellite imagery may represent a significant opportunity for application and should be explored further.

Manned aircraft

Manned aircraft including helicopters and fixed-wing aircrafts can also be used for tracking of animals. The benefits of this method, particularly over satellite imagery, is that the flight times and altitudes can be customised to the producer's needs. Furthermore, the resolution of images is often higher than that of satellite images (Wang et al. 2019). Limitations of this tracking method include the high cost for implementation, including costs of aircraft maintenance, labour and time. Furthermore, flying of aircraft can be considered dangerous, with pilots often required to fly in potentially unsafe environments to locate the livestock (Higgins and Nolan 2018).

Unmanned aerial vehicle (UAVs)

The use of UAVs or 'drones' in the agricultural sector has been growing steadily throughout the past decade. Two major types of drones are available for agricultural applications: rotary and fixed-wing. Rotary UAVs are portable, cost-effective and have the added benefit of being able to hover over a point of interest. However, they are limited in terms of their sensor payload capabilities and are unstable in bad weather (Barbedo and Koenigkan 2018). In contrast, fixed-wing UAVs have lower power requirements, are better suited for poor weather and are able to carry more sensors than rotary devices. The disadvantages are however, that they are expensive and more difficult to operate (Barbedo and Koenigkan 2018).

UAVs are often fitted with a number of imaging technologies, though only a select few are suitable for animal tracking.

- Thermal or infrared cameras are useful for differentiating between animals and the ground. They are best utilised in the morning and evening when the temperature difference between the two is the greatest (Keates et al. 2019).
- Multispectral cameras capture images at specific wavelengths. These can be used to identify and count animals based on the different spectral characteristics of different species (Barbedo and Koenigkan 2018).
- Hyperspectral cameras provide higher spectral resolution images than multispectral cameras and are generally unnecessary for animal detection and counting purposes. However, it is possible that these cameras could assist with detection of more subtle traits, including animal breeds and/or the presence of disease (Barbedo and Koenigkan 2018).
- Video cameras provide single output files and are useful when tracking a specific individual.

For accurate tracking of animals, images collected by UAVs need to be combined (known as 'mosaicking') to allow the entire scene to be interpreted (Barbedo and Koenigkan 2018). This process is computationally expensive and thus may not be appropriate if timely tracking results are required. In addition, mosaicking relies on matching of distinctive features, and thus is limited in homogenous environments, such as pasture or rangelands (Barbedo and Koenigkan 2018). Tracking of animals may also be hindered by the natural movement of animals over time. That is, animals may appear in more than one image or may not appear at all (Witczuk et al. 2018). Finally, trees and dense scrub may hinder the ability to identify animals. Nevertheless, if these limitations are adequately considered, the use of UAVs for animal tracking shows promise.

In an MLA funded study of UAVs, the technology was found to assist in the identification of livestock in Northern Queensland (Keates et al. 2019). Overall, the identification algorithm was found to be 98% accurate, with limitations associated with differentiating animals when they were grouped tightly together. It is important to state that this accuracy was for the detection of cattle within the environment, not individual cattle themselves. This represents a limitation of the technology in that only groups of animals are able to be adequately monitored, rather than individual tracking. In this report, Keates et al. (2019), concluded that animal condition may be subjectively assessable if the animals were continually monitored over short periods. Again, this would only be achievable on a herd level.

The key challenges identified for application in extensive Australian agriculture were issues surrounding flight time and the ability to cover large distances (Keates et al. 2019). This was addressed by an initial concept of autonomous recharge stations, although these were found to be inadequate due to the time for recharge (2 h). Based on this, a new design was tested, with alternate charging of spare batteries allowing for redeployment within 15min of returning to the base station. In this situation, the UAVs were able to cover 180km prior to recharging. In circumstances where construction of a base station is not possible, alternative power sources were also examined, including a solar-charged UAV which was able to cover 350km over a 7.5h period, and a UAV fitted with a petrol engine, with a projected endurance of 800km over 15h.

Another key challenge regarding the use of UAVs are the rules and regulations surrounding permitted flight locations and licensing requirements. These are governed by the Civil Aviation Safety Authority (CASA 2020). In addition to operator licence requirements, UAVs used for work purposes also require registration which must be renewed annually. Furthermore, UAVs are generally required to be kept within a line of sight to the operator, which greatly restricts their use on extensive farming systems. To improve the safety of use, automatic dependant surveillance broadcast (ADS-B) equipment can be used to broadcast the precision position of the UAV to aircraft in the vicinity, notify private aircraft operators in the area as well as issue a Notice to Airmen (NOTAMs) (Keates et al. 2019). However, it is expected that these restrictions will be prohibitive to future commercialisation efforts.

Stationary cameras

Stationary cameras can also be used for tracking purposes. These differ from the previously mentioned imaging technologies in that they offer image analysis from numerous perspectives and angles (i.e. not just vertically down).

Stationary cameras are commonly used in a number of industries, including tracking of pedestrians or vehicles. For pedestrian tracking, active deformable models are one method that can be used to separate the human figure from the slowly evolving ground image (Sullivan et al. 1995). This method has the added benefit of being able to manage change in figure shape during movement and the obscuring of certain body features. Tracking of animals by stationary camera is also common in the poultry industry (see Sassi et al. (2018) for a review). For example, video images can be used to assess the activity of birds and their corresponding gait score (Kestin et al. 1992). Although not strictly used for location-based monitoring, stationary infrared camera analysis is also used in the dairy industry for oestrus and mastitis detection (Naas et al. 2014).

In real-life scenarios, and perhaps more relevant to the tracking of extensive livestock, the ability of the stationary camera to ‘view’ the individual and track their movement over time and space is crucial. This can be assisted by various ‘pan-tilt-zoom’ functions that widen the area that can be effectively monitored (Veluchamy and Anderson 2011). Although this functionality is useful, the application of stationary cameras more broadly is limited by the size of the area to be covered. To address this, animals may be contained within an area to ensure adequate opportunity for viewing. Benvenutti et al. (2015) utilised three time-lapse capable cameras to assess water usage by Brahman cattle in a 20 x 30m enclosure. Overall, Benvenutti et al. (2015) reported a high accuracy for counting of animals when the cameras were 7 or 35m from the enclosure, concluding that an ideal camera position was directly overhead to ensure no animals were hidden. In another study of dairy and beef cattle (Dao et al. 2015), real-time tracking of animals was also shown to be possible using multiple cameras and was able to cope with situations where cows left and re-entered the scene. These studies broadly prove the capacity for livestock tracking using stationary cameras. However, in each situation the animals were maintained in a pen. This suggests limitations of use of this technology in more extensive environments where animals may not be necessarily contained. The use of this technology should not be immediately dismissed however, with the use of stationary cameras in high value resource points (e.g. watering points) feasible. This could be then be coupled with RFID technology and/or facial recognition for individual location tracking (see Sections 0 and 0).

Attribute tracking (what is the animal doing?)
In addition to knowing 'where' the animal is located within their environment, the ability to monitor 'what' the animal is doing will provide critical data for use within the integrity system. This is of particular relevance to disease outbreaks and the ability to identify and verify product claims such as "grass fed beef". The following section reviews the currently reported sensor platforms that have been applied to monitor the activity, behaviour and state of livestock.

Motion sensors
Motion sensors encompass a variety of devices which are designed to measure the animal's movement in some way. Motions sensors include (but are not limited to) mechanical pedometers, accelerometers, magnetometers, gyroscopes, inertial monitoring units (IMUs) and mercury tilt devices.

- Mechanical pedometers contain a metal pendulum that moves back-and-forth with movement. This movement effectively opens and closes an electrical circuit within the device, allowing for a 'step-count' to be determined (Yang and Hsu 2010). Pedometers are considered the most basic type of motion sensor and are relatively cheap to implement. However, they are unable to measure intensity of movement.
- Accelerometers, or more specifically micro-electromechanical system (MEMS) accelerometers, measure the linear acceleration experienced along one or many axes. Other accelerometer types include piezoresistive and piezoelectric accelerometers, though these are less commonly applied in livestock research due to issues associated with temperature sensitive drift and an inability to detect postural change (Yang and Hsu 2010).
- Magnetometers measure the direction, strength or relative change in the magnetic field around one or many axes. They are used to measure the trajectory of animals (Sakai et al. 2019).
- Gyroscopes measure angular velocity around one or many axes (Yang and Hsu 2010)
- IMUs are a single sensor unit that contains an accelerometer, magnetometer and gyroscope. This effectively allows monitoring on nine different axes (Sakai et al. 2019).
- Mercury tilt devices are more traditional research-grade devices which allow monitoring of the animal's posture (e.g. standing or lying). Due to their large size and relatively awkward design, these are not considered appropriate for commercial application.

Behaviour and movement can be used to derive various details of the animal state. The above motion sensor technologies have largely been proven as appropriate methods of monitoring animal behaviour, including being able to autonomously detect the animal's activity through comparison with known visual observations. For example, Robert et al. (2009) reported an accuracy of 98% when using accelerometers to detect lying and standing activity of beef cattle. A similar result has been shown in sheep, with 91% accuracy of posture detection, and 98% accuracy in detecting active and inactive behaviour using ear tag-attached accelerometers (Fogarty et al. 2020c). The following table has been provided to demonstrate the potential use of motion sensors in commercial situations (Table 4). It is not intended to be an exhaustive list, but rather to present various example applications.

Table 4 Example applications of motion sensor tracking in livestock research: ACC = accelerometer; IMU = inertial monitoring unit; MAG = magnetometer; Mult = Multiple; Oth = Other

Application	Species	Sensor	Research focus	Reference
General behaviour	Cattle	ACC	General behaviour detection	Hokkanen et al. (2011) Kuankid et al. (2014)
		MAG	Movement and behaviour model	Guo et al. (2009)
	Sheep	ACC	Detection of general behaviour	Alvarenga et al. (2016) Barwick et al. (2018b) Fogarty et al. (2020c)
		IMU	Impact of device on animal behaviour	Hobbs-Chell et al. (2012)
		Oth	General activity	Thomas et al. (2008)
Animal health and disease	Cattle	ACC	Disease detection	Tobin et al. (2020)
		ACC	Drinking behaviour	Williams et al. (2019)
	Sheep	ACC	Disease detection	Cronin et al. (2016)
		ACC	Lameness detection	Barwick et al. (2018a)
		ACC	Worm burden & animal activity	Ikurior et al. (2020)
Reproductive behaviour	Cattle	ACC	Bull mounting	Abell et al. (2017)
		ACC	Parturition behaviour	Miller et al. (2020) Krieger et al. (2017)
	Sheep	ACC	Parturition behaviour	Fogarty et al. (2020b)
Social behaviour	Sheep	ACC	Suckling behaviour	Kuźnicka and Gburzyński (2017)
Welfare	Sheep	Mult	Review paper	Fogarty et al. (2019)
	Multiple	Mult	Review paper	Rushen and de Passille (2012)

Location-based sensors

In addition to providing location estimates for the animal, location-based data can be further analysed to monitor various animal attributes. These applications are varied and are dependent on chosen sensor type. The following table has been provided to demonstrate the flexibility of location-based sensors (Table 5). It is not intended to be an exhaustive list, but rather to present various examples of these applications.

Table 5 Example applications of location-based attribute tracking in livestock research: GNSS = Global Navigation Satellite System; IC = Infrared camera; PL = Proximity logger; SC = Stationary camera; Mult = Multiple

Application	Species	Sensor	Research focus	Reference
Animal health and disease	Cattle	GNSS	Impact of pesticide treatment	Trotter et al. (2018)
		SC	Water point usage	Benvenutti et al. (2015)
		IC	Mastitis detection	Naas et al. (2014)
	Sheep	GNSS	Predation detection	Manning et al. (2014)
		GNSS	Impact of Phalaris Staggers	Trotter et al. (2018)
Reproductive behaviour	Cattle	GNSS	Parturition behaviour	Florcke and Grandin (2014)
	Sheep	GNSS	Oestrus behaviour	Fogarty et al. (2015)
		RFID	Oestrus detection	Alhamada et al. (2017)
		GNSS	Parturition behaviour	Dobos et al. (2014) Fogarty et al. (2020a)
Social behaviour	Cattle	PL	Pregnant cattle associations	Swain et al. (2015)
	Sheep	PL	Ewe-lamb interactions	Broster et al. (2012)
Welfare	Sheep	Mult	Review paper	Fogarty et al. (2019)
	Multiple	Mult	Review paper	Rushen and de Passille (2012)

Live weight and body condition

Collection of animal live weight or body condition scores (BCS) are important for animal management purposes. Live weights can be collected manually at key management points throughout the production cycle. In addition, walk-over-weigh (WoW) technology can be used for remote automatic capturing of live weight. WoW systems include a race with weight platform, an RFID reader and a power supply (e.g. solar panels with supplementary battery). The systems are generally installed at watering points in the paddock or areas of supplement feed, with livestock required to pass through the WoW system to access desired resource (Trotter 2018). In an MLA funded review of WoW technology, Swain (2017) reported the use of WoW for automatic recording of calving, age of puberty and potential oestrus events. The report concluded that while commercial versions of the technology were available (TruTest 2020), ongoing industry investment was still necessary to improve the reliability and price of the system. In addition, producer concern regarding lack of algorithm transparency was noted as a potential limitation to commercial uptake.

Automated weigh systems are also available through other means. For example, the Optiweigh system is a smaller system where cattle weigh themselves by placing their front feet on the platform (Optiweigh 2019). The system is able to be used with and without RFID tags, although they are required if the producer wants to record individual liveweight.

For automated BCS of animals, imaging technology can be utilised, including 2D, 3D and thermal imaging (Song et al. 2019). Commercial versions of this technology are utilised in dairy systems e.g. DeLaval (Tumba, Sweden), Biondi Engineering SA (Cadempino, Switzerland) (O'Leary et al. 2020). These systems extract body condition-related features, including bony distinctions and surface depressions (Song et al. 2019). Automated BCS is not yet widely used the beef or sheep industry, although research regarding the feasibility of application has been conducted (Burke et al. 2004; McPhee et al. 2017). Notably, problems associated with accurate BCS in sheep are noted, especially in the presence of thick wool (Burke et al. 2004).

Internal animal sensors

Internal animal sensors can be broadly divided into two categories: ones that inserted subcutaneously and ones that are held in the rumen (Trotter 2018). Subcutaneous microchips have been used to measure body temperature, although they may be impacted by ambient temperature due to the proximity to the surface (Lee et al. 2016). Rumen sensors can also be used to monitor internal body temperature, in addition to biochemical states including pH (Zhang et al. 2018). Generally, internal body monitoring is targeted at early detection of disease and other physiological events. More recently, rumen accelerometers have also been employed to monitor rumen movement as a measure of rumen health (Nogami et al. 2017). While both form factors show potential monitoring capabilities, there are concerns regarding the retrieval of devices at processing to prevent them entering the human food chain and damaging offal processing equipment.

Heart rate monitors
Heart rate (HR) monitors can be used to monitor various aspects of animal health. For example, HR can be related to various physiological states, including simulation of both the sympathetic (fight or flight) or parasympathetic (rest and digest) nervous systems. HR modelling has also been used as a method of measuring mental stress in race car drivers (Taelman et al. 2016) and horses (Norton et al. 2018). Although still broadly applied as research-grade sensor, HR monitoring has been suggested as uniquely able to monitor mental aspects of animal welfare (Fogarty et al. 2019). For this reason, commercial application of these sensors should not be immediately dismissed, particularly considering the advancements in optical HR monitoring technologies that have become widely used for human wearables (e.g. Apple Watch, FitBit, Garmin Activity Trackers) (Valenti and Westerterp 2013).

Data communication
To ensure timely transfer of animal telemetry information, adequate methods of data communication are essential. One of the simplest methods for categorising these technologies is to consider their transmission distance (Table 6). The specifics of each will be discussed in the following sections. Many of these communication technologies are governed by the Institute of Electrical and Electronics Engineers (IEEE) standards (IEEE Standards Association 2020).

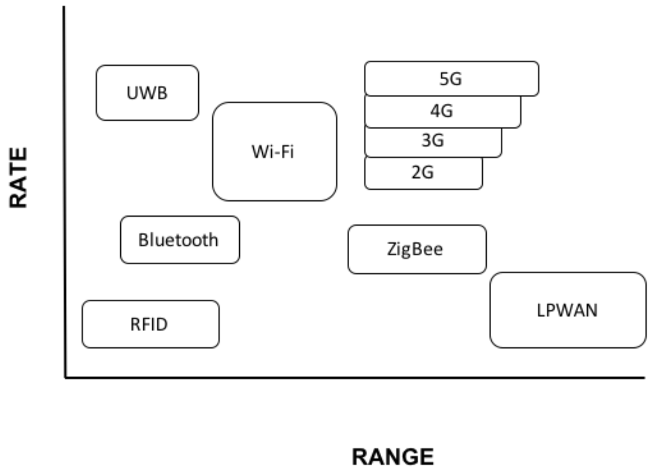
Table 6 Transmission distance of various communication technologies (Feng et al. 2019)

Transmission distance	Communication technology
Short-range (≤ 10m)	• RFID • UWB • Bluetooth (earlier versions)[1] • NFC
Medium-range (10 – 100 m)	• Wireless Local Area Network (Wi-Fi) • ZigBee
Long-range (≥ 100 m)	• Cellular networks (3G, 4G, Long Term Evolution (LTE), 5G etc.) • Low Power Wide Area Network (LPWAN) • Direct to satellite

[1] Bluetooth has a typical range of up to 10m, although newer versions (e.g. Bluetooth 5) can have a range of up to 400 m

In addition to transmission distance, the rate of data transfer is considered another critical factor. The trade-off between transmission distance and rate of transfer is shown in Figure 3.

Figure 3 Schematic diagram of the range and data rate transfer of various communication technologies. Adapted from (Feng et al. 2019)



For further detail of many of these technologies, and for specific details regarding implementation in Australia, please refer to MLA publication B.GBP.0041 (Leedham and Siebert 2019).

7.3 Short-range communication

Radio-based and UWB

As previously identified, radio (i.e. passive or active RFID at different frequencies) and UWB have the capacity to transfer data over short distances (typically ≤ 10m). These technologies have been extensively discussed in Sections 7.1 and 7.2.

Bluetooth

As discussed in Section 7.1, Bluetooth technology can be used in two forms: traditional Bluetooth and BLE. Both versions transmit at 2.4 GHz frequency over short ranges (Feng et al. 2019), though BLE requires less power overall and is therefore preferred when the application requires battery power over an extended period of time. Bluetooth is supported by a number of operating systems, including Android, iOS and Windows. In comparison to traditional RFID which can only transfer limited information, Bluetooth technology can transfer larger amounts of information at faster rates. In a livestock context, Bluetooth is often used to facilitate data transfer between RFID readers or weigh systems and a user device (Pretty and Moroz 2013). Use of Bluetooth for localisation has also been conducted (Bloch and Pastell 2020). In research by Nagl et al. (2003), Bluetooth was also successfully utilised to facilitate data transfer from various on-animal sensors, including GNSS, to a local base station.

NFC

As previously identified in Section 7.1, NFC is a type of passive HF technology commonly used for transfer of information over short distances (up to 10cm). For example, NFC is commonly used to facilitate contactless payment or building access control. It is a passive type of technology, where the initiating device (e.g. smart phone) generates the RF field that powers the passive target. NFC is not commonly used in livestock situations, although it has been proposed as a method of traceability in the pig meat supply chain (Pigini and Conti 2017). It has also been proposed for use in other industries, including wearable healthcare devices (Cao et al. 2019).

7.4 Medium-range communication

Medium-range communication technologies have transfer capabilities between 10 to 100m.

Wi-Fi can be used to connect multiple types of devices through an ad-hoc network. Wi-Fi is maintained under the IEEE 802.11 standard (IEEE Standards Association 2020). Wi-Fi can communicate at multiple frequencies, including but not limited to 2.4 GHz, 5 GHz, 6 GHz and 60 GHz. As Wi-Fi was developed to extend wired local area networks such as Ethernet (Wang et al. 2006), use of this communication technology is often limited to computer-based systems. In addition, power consumption is high and battery life is a concern (Ruiz-Garcia et al. 2009). Nevertheless, Wi-Fi has high bandwidth and can thus transfer high volumes of data in relatively short periods of time (Feng et al. 2019).

In an MLA study of telecommunications access in Northern Australia (Leedham and Siebert 2019), the high cost of Wi-Fi was noted. In this report, a property wide Wi-Fi network (based on a property size of 50 x 100km) was estimated to cost approximately $500,000, requiring 30-40 towers to support the services. In the report, the author's state that due to the high bandwidth technology and subsequent high-power requirements, they are generally considered unsuitable for direct connectivity to battery operated sensors, including ear tags. Instead, the author's state that the technology is more suited as a complementary technology for connectivity to LPWAN gateways.

ZigBee

ZigBee is another medium-range communication technology with relatively long battery life, small form factor and high reliability. It is governed under the IEEE 802.15.4 standard. The technology is used at three frequencies, 868 MHz, 915 MHz and 2.4 GHz with a data rate between 20 and 250 kbps (Wang et al. 2006; Feng et al. 2019). In comparison to Bluetooth, ZigBee has superior power management, higher network flexibility and transmission of information over longer distances (Ruiz-Garcia et al. 2009). However, it is not directly compatible with Android, iOS or Windows (Link Labs 2020). When compared to Wi-Fi, ZigBee has superior battery life and is more cost-effective (Wang et al. 2006).

ZigBee devices typically transmit data in a 20m range. However, they can transfer data over longer distances through utilisation of a mesh network (Wang et al. 2006). In this way, the devices transfer information through intermediate devices to reach more distant ones. This helps to facilitate lower power consumption, as not all devices need to be running at once.

ZigBee has been used in livestock research, including sheep (Nadimi et al. 2012) and cattle (Huircán et al. 2010) studies. Nadimi et al. (2012) utilised a ZigBee-based cellular wireless sensor network to monitor head movements of sheep using accelerometer technology. Huircán et al. (2010) used ZigBee technology for localisation of grazing cattle based on the link quality between the router and end device. This is similar to RSS used for RFID localisation. Overall, both publications support the use of ZigBee for communication of livestock data. Feng et al. (2019) also supports the use of ZigBee for livestock tracking based on the low power and low cost of implementation.

7.5 Long-range communication

Long-range communication technologies include cellular networks and LPWAN. These have transfer capabilities over 100m, although they are generally used over much longer distances (i.e. > 1km).
Cellular networks (3G, 4G, Long Term Evolution (LTE), 5G etc.)

Cellular networks can be considered Wide Area Networks (WAN) and encompass various iterations of the technology (3G, 4G, LTE, 5G etc.). Cellular networks are provided through the presence of base stations at strategic locations (Leedham and Siebert 2019). In general, cellular networks provide high data transfer rate and good mobility. However, they also have high-power consumption. This differs from other long-range technologies including LPWAN which have relatively low power requirements (Feng et al. 2019). In addition, access to cellular networks is limited to areas with adequate coverage, which is often not the case in rural or remote areas (Leedham and Siebert 2019). Cellular phone repeaters can be installed to magnify the range of existing networks, however only work in areas with existing coverage (Leedham and Siebert 2019).

Low Power Wide Area Network (LPWAN)

LPWANs are an emerging method of wireless communication which allow transfer of data across long distances (Germani et al. 2019). LPWANs were designed for long-range communication between objects, utilising low bit rate transfer of information and thus having low power requirements. Various versions of LPWANs are available, including LoRa, SigFox and Narrow Band Internet of Things (NB-IoT) (Germani et al. 2019). These versions all slightly differ in their capabilities. For example, LoRa is established at 869-915 MHz, with a data rate of 50 kbps. In comparison, NB-IoT utilise various LTE frequency bands, with a data rate between 160-250 kbps (Feng et al. 2019).

In rural areas, coverage distance for LPWANs is usually reported in excess of 10km, although reports of up to 40km have been made (Leedham and Siebert 2019; Maroto-Molina et al. 2019). In addition, a single gateway is often sufficient to manage a large number of end devices (e.g. on-animal sensors) with little maintenance (Germani et al. 2019; Waterhouse et al. 2019). This makes these technologies particularly attractive for development in extensive livestock systems where animals may be spread over large distances. In work by Feng et al. (2019), both LoRa and NB-IoT were reported to offer coverage distance over 15km, with acceptable data transfer rate and relatively small power consumption. Between the two, disadvantages of NB-IoT were noted as a high monthly subscription cost, whereas LoRa was considered more expensive in terms of maintenance. In another study, Terrasson et al. (2016) successfully utilised SigFox to facilitate transfer of GNSS and accelerometer data from cattle grazing mountain pastures in France and Spain. Of note, Maroto-Molina et al. (2019) also used SigFox technology to facilitate communication of GNSS location and Bluetooth proximity data for grazing sheep and cattle in Spain. In this study, the author's attempted to reduce the cost of implementation by fitting only sentinel animals with the more expensive GNSS, with the location of the remaining herd members determined through proximity information to each sentinel. Overall, Maroto-Molina et al. (2019) reported that a smaller number of GNSS devices were required to monitor the whole sheep flock due to their tendency to remain cohesive (10 GNSS were required to detect all 25 Bluetooth tags on a daily basis). A larger number of GNSS were required to adequately monitor the cattle due to their tendency to distribute themselves across the paddock (25 GNSS were required to detect all 25 Bluetooth tags on a daily basis). A comparison of LPWAN technologies (LoRa, SigFox, NB-IoT) is presented in Table 7.

Table 7 Comparison of LPWAN technologies [adapted from (Nair et al. 2019)]

	LoRa	SigFox	NB-IoT
Interference immunity	Very High	Very High	Low
Maximum data rate	50 kbps	100 kbps	200 kbps
Bi-directional	Yes/Half-duplex	Limited/Half-duplex	Yes/Half-duplex
Power consumption	Low	Low	Very low
Security	Low	Low	Very high
Bandwidth	250 kHz and 125 kHz	100 kHz	200 kHz
Technology	Proprietary	Proprietary	OpenLTE

Range	5 km (urban) 20 km (rural)	10 km (urban) 40 km (rural)	1 km (urban) 10 km (rural)
Battery lifespan	10 years	10 years	15 years

7.6 Direct to satellite

Satellite technology was initially developed for transmission of large volumes of data from relatively few devices. However, as the Internet of Things (IoT), including sensor technology, becomes more pervasive, there is increasing opportunity for use of satellite communication for smaller IoT devices. Satellite communication can be conducted in two main ways. Transmission direct-to-orbit is the most direct method of transfer, but it is expensive and requires significant power. The second option is to aggregate data at local wireless nodes prior to using the satellites as a backhaul service. The latter option is preferred where there is critical density of sensors. However, it is limited in situations where the sensors move throughout the environment (Myriota 2017). Satellite technologies offer the almost universal coverage across Australia (Xinova 2019).

Myriota is an Australian-based company that uses small, low cost transmitters to facilitate transfer of small volumes of data direct to satellites (Myriota 2017). Utilising a constellation of low-orbit nanosatellites, this reduces the need for additional ground-based infrastructure such as gateways or towns. Once received by the satellite, the data is processed and hosted in the cloud (Myriota 2017). The benefit of low-orbit satellites is the reduced physical distance between the device and the satellite, requiring less power for data transmission (Xinova 2019).

Optus operates a fleet of five geostationary satellites over Australia and New Zealand with access to another nine third-party satellites in the Pacific and Indian Ocean regions (Wang et al. 2009), which supports IoT and machine to machine (M2M) applications. A British satellite telecommunications system, Inmarsat (Abutaleb et al. 2006), also provides data and voice communications via 12 geostationary satellites, providing satellite connectivity to Vodafone's IoT platforms all over Australia including regional areas.

8. Future integrity systems structure, critical evaluation, and potential scenarios

Given the various stages of development of different platform components described in Section 7, the following section provides a broad overview of potential future opportunities for the NLIS and broader integrity systems to integrate these emerging solutions. These opportunities will be described based on a scaled-up approach using a least-to-most complex framework. Options for improvement range from relatively simple modifications to the current system, through to more complex future visions of what might be achieved when new sensor platforms have been proven reliable. These future scenarios are largely focused on the use of on-animal sensor technology, primarily in an ear tag form factor. A discussion of the relative strengths of this form factor follows, including comparison against some of the other platform component options described in Section 7.

8.1 Optimal form factors and deployment modes

Based on the identified technologies in Section 7, there are three main groups of sensors available for development of future integrity systems: (i) on-animal; (ii) in-animal; and (iii) off-animal sensor systems.

- On-animal sensor systems appear to be most appropriate for future application. This is based on their established acceptance within the industry (i.e. ear tagging), the ease of deployment, and the challenges associated with the more invasive in-animal sensors (e.g. implantable devices).

- In-animal systems that have been considered include boluses and/or implants. Boluses are currently considered an appropriate method of identification, although difficulties with recovery at slaughter have been reported (Fallon 2001; Gaunt 2007). Surgical implants are not currently considered a viable option due to difficulties with application and food safety issues.

- Off-animal sensor systems are mostly based on image analysis and may have some potential application for future integrity systems. In general, image-based systems such as stationary cameras and satellite imagery, manned or unmanned aerial vehicles are limited in their ability to identify individual animals. There are also barriers to implementation including cost and access to reliable technology. This is also the case for many biometric identification methods, including muzzle prints, eye-based techniques and facial recognition, which are considered prohibitive in terms of ease of application and commercial potential. The benefit of these technologies over image-based identification is the ability to identify individuals. This is a critical aspect of traceability and thus should not be completely dismissed. However, these systems require more proof of concept research, particularly over much larger data sets before they can be considered a viable option for future integrity system integration.

There is one exception to off-animal sensor systems that needs to be explored. Satellite-based image analysis of animal numbers may have reasonable application for quantification of cattle numbers at a property level. Again, although not able to identify individuals, the use of this technology in systems where individual tracking is challenging (e.g. Northern Australia/ pastoral areas) may be viable. This is discussed further in the following section.

DNA testing and tissue sampling is another potentially valuable addition in terms of identification through the entire value chain. Tissue sampling at time of tagging allows for both DNA identification and disease profiling and may enable a more stringent method of identification and individual traceability than currently possible. This has already been shown in other market sectors, including pork products from Dutch retailer Albert Heijn, which utilises DNA Traceback® from IdentiGEN to facilitate fork-to-farm traceability (Fortune 2020). IdentiGEN DNA Traceback® is also available for beef products (IdentiGEN 2020).

8.2 Future on-animal identification and traceability platforms

The following section focuses on the use of on-animal identification and tracking systems and provides a broad overview of potential future opportunities for the NLIS and broader integrity systems. Four approaches, each with increasing complexity, are detailed and discussed, including the benefits, challenges and technical feasibility associated with each (Table 8). It is presumed that the benefits of each additional level are inclusive of those achieved by the previous level. Two additional platforms are also considered; tissue sampling for DNA traceability and satellite remote sensing for animal counting. These could be applied as additional tools at any level.

Level 1 - Future platform that continues to use current RFID technology as the core identification platform along with more advanced tag and reader technologies

A simple advancement of the current NLIS platform would be the integration of automated RFID reader technology (with a data transfer system) at critical points along the pre-farm gate supply chain. This information could validate animal-to-animal associations and if linked to positioning technology (e.g. known location of the reader itself and/or GNSS in reader system) provide information on the location of livestock.

A potentially useful development would be the integration of an RFID reader, GNSS positioning and data transfer system on all animal transport vehicles. Animals could be automatically scanned on and off the vehicle and their location recorded. This would provide key validation data for the National Vendor Declaration (NVD), including both the individual animals being transported and pick-up/delivery site. It could also trigger automated eNVD's, requesting further information from the producer (e.g. Hormone Growth Promotants (HGPs) treatment, Extended Residue Program (ERP) status) where one has not already been provided. From here, the integrated positioning system could monitor the location and transport pathway of livestock, providing valuable information for some integrity system functions (particularly biosecurity).

Using current short-range passive LF RFID tags, readers will need to be positioned near the entrances to transport vehicle. This may prove to be challenging and impractical. A more practical solution, development of a higher frequency passive RFID tags (i.e. HF or UHF) may be more plausible. Use of higher frequency tags will allow for transmission of identification data over greater distances (up to 3m). Furthermore, HF and UHF are more appropriate for identification of multiple animals simultaneously (as would be expected when loading or unloading a transport vehicle). Ear tags would be the preferred form factor due to issues with HF and UHF lower penetrative ability and water interference, making them less suitable for a bolus or implantation (Doğan et al. 2017). Other considerations for implementation of this system include energy management of the RFID reader and positioning device. Most likely, these devices would require direct power from the vehicle itself, although battery and solar changing is plausible. Data communication could be achieved through cellular networks or satellite connectivity.

Level 2 - Future platform that incorporates active RFID technology with ability to broadcast to greater distances

A potentially valuable change to the current system would be the development of an RFID ear tag that is able to initiate data transmission over a significant distance. This would require development of an active RFID tag (i.e. a tag that contains its own power source). This could be achieved by use of a battery, but capacitor-based systems with solar charging could also be explored. Incorporation of the power source will enable the device to periodically transmit a radio broadcast. This differs from passive systems identified in Level 1 which are reliant on external stimulation from the reader.

There are two distinct communication options within this solution: (i) a device of medium-range (10 – 100m) such as Bluetooth or Wi-Fi; or (ii) a long-range system(> 100m but preferably over 1km) for example cellular networks, LPWAN or Taggle proprietary radio (Taggle 2019).

The medium-range solution could provide more reliability to the Level 1 system proposed above, allowing for periodic transmission of the animal's identification and subsequent location tracking [based on range-based method of trilateration e.g. RSS, time of arrival (see Section 0)]. However, it is unknown whether the benefits gained would outweigh the expected cost of development and implementation. Comparatively, a long-range solution could provide identification of animal location at a coarse spatial resolution, both on-farm level and during transport. However, this option would require the widespread deployment of antenna infrastructure. Some examples of commercial options in this space (e.g. the Taggle proprietary system) already have networks of towers across some regions which demonstrates this functionality. Use of cellular networks for long-range data transfer is also possible, provided that sufficient network coverage is available. Options for improved telecommunications in Australia have been extensively discussed in Leedham and Siebert (2019).

Level 3 - Future systems that incorporate basic animal activity monitoring technologies

Under this platform, low power sensors could be used to facilitate basic animal activity monitoring. For example, accelerometer technology is relatively low powered, and its capacity to monitor various aspects of activity has been broadly proven (see Section 0). Use of proximity data, through Bluetooth or BLE, could also be used to facilitate localisation of animals, both in terms of animal-animal tracking (if both animals are fitted with a sensor) or proximity to points of interest (e.g. a water point with a stationary sensor). Similar to the previous options, considerations for implementation include energy management of devices. Again, this may be simply achievable through the use of a battery, however more renewable sources such as solar charging could also be explored, particularly if the tags are expected to achieve lifelong monitoring. Data communication could be achieved through medium-range systems (e.g. Wi-Fi or node-hopping ZigBee), or more long-range systems (e.g. cellular networks, LPWANs, satellite connectivity).

Level 4 - Future systems that incorporate advanced location and activity along with remote communication capabilities

The most comprehensive platform considered feasible is an on-animal sensor system recording location data (most likely through GNSS), activity data (most likely through accelerometers) and proximity measures (most likely Bluetooth or BLE). Ideally this system would transfer data via satellite connectivity although local area networks or cellular networks could provide feasible solutions in some regions.

Consideration needs to be given to deployment of sentinel systems in this context. Not all animals may need to be tracked at this level to provide valuable information for use in various integrity system functions (e.g. biosecurity disease detection and management).

The on-demand location, activity and state data provided by such a system would prove valuable across a range of future NLIS and integrity system functions, from biosecurity, food safety to validation of welfare and sustainability claims as well as provide significant benefit to producers for on-farm applications.

Additional platform – Tissue sampling and DNA identification

This particular option is considered an additional platform that could be aligned to any of the previously identified systems. Tissue sample would be conducted at tagging [e.g. through the Allflex® tissue sampling method; Allflex (2019)], after which the samples would be sent for storage. This simple addition could provide key data for use in disease monitoring, as well as animal and animal product identification further down the supply chain. This process would require sufficient infrastructure for archiving of samples, although the benefit would be that samples would only be analysed if required. An extension of this would be the automatic processing and storage of DNA information on a centralised database. This would facilitate more rapid tracing in the event of a traceability event, although issues associated with costs of implementation would need to be carefully considered.

Additional platform – High resolution remote sensing imagery analysis for property level livestock counts

As previously identified in Section 8.1, deployment of on-animal identification and monitoring systems remains a significant challenge in some parts of Australia. A good example of this is Northern Australia and other pastoral areas where beef breeding operations are based on large landscapes and exact livestock numbers cannot easily be determined. There may be an opportunity for remote sensing-based image analysis to provide some limited but valuable data for integration into a traceability system. In areas where individual animal tagging is currently achievable (e.g. southern high rainfall beef operations) the development of a remote sensing-based animal counting system could support the current PIC based location monitoring system and detect anomalies.

Flexible approaches that blend strategies

It should be noted that the above options have been created with relatively clear boundaries between each scenario. However, there is likely to be opportunities for hybrid solutions that use different components of these various levels to provide the desired information. One key variation that should be discussed is the use of sentinel systems. In this approach a small number of animals are fitted with higher-resolution monitoring systems (as described Level 3 or 4) while other animals are identified with a lower level technology. The sentinel animals provide key information for some functions within the integrity system but at a much lower roll out cost. Reference will be made to this in the following sections where relevant.

Table 8 Potential future traceabilty platforms, described from least-to-most complex and including a preliminary overview of their strengths and weaknesses. A complete asessment of how each platform might be applied to the various functions of the NLIS is provided in Section 9

Platform	Details	Identification	Traceability – location resolution	Traceability – Attribute tracking	Strengths and weaknesses	Technical feasibility and likely time to market
Current system	RFID tags (or visual tags for non-Victorian sheep). NVD for stock movement.	Short-range LF RFID.	To property level based on PIC and NVD.	Minimal. Although, this system can be used with manual data input by producers. Automated data collection is available with appropriate infrastructure (e.g. WoW).	**Strengths** Currently accepted. **Weaknesses** Not useful until animal tagged.	Currently implemented.
Level 1 – Transport tracking	Current NLIS with addition of RFID reader panels on all livestock transport linked to GPS. Option for improvement by use of HF & UHF tags.	Short-Range LF RFID as per current NLIS or incorporation of improved HF/UHF system.	This system provides point of entry/exit geolocation for livestock on vehicular transport. It also provides precise geolocation of animals during transport and where connectivity (e.g. cellular network, satellite) is available could deliver this in real-time.	As per above. Some additional data (e.g. time in transport) could also prove valuable in terms of addressing key industry issues (e.g. dark cutting from poor transport practice to slaughter).	**Strengths** Improves records of animal location. Removes ambiguity around actual locations of PICs and multi-site PICs. Could be used to generate automated alerts to remind producers to submit NVDs. **Weaknesses** Not useful where animals moved on foot.	Would require technical and engineering development and cooperation with transport companies. The viability of scanning animals onto trucks also needs to be explored.

Platform	Details	Identification	Traceability – location resolution	Traceability – Attribute tracking	Strengths and weaknesses	Technical feasibility and likely time to market
Level 2 – Active medium or long-range RFID	Active tag periodically transmits identification. Network of towers collects data.	Longer range RFID.	Long-range broadcast would enable coarse positional tracking on-farm and during transport.	As per above.	**Strengths** Animals do not need to pass a reader to stimulate the passive tag. **Weaknesses** Requires terrestrial infrastructure.	Taggle ear tags have demonstrated the potential for this platform. Key issues including tag retention and affordability remain.
Level 3 – Basic behavioural monitoring	Tag collects data from low power sensors (accelerometer and proximity) and either periodically transmits the data or downloads upon connection with a reader.	Medium or long-range RFID.	Proximity-based sensing based on relative position to other animals and/or places of interest.	Basic behavioural analysis of data could provide insights for a range of NLIS functions. For example: aberrant behaviour for disease detection (for biosecurity purposes), grazing and ruminating behaviour (market claim validation), socialisation analysis (welfare validation).	**Strengths** Inclusion of attribute tracking for improved animal monitoring. Opportunities for animal health and/or welfare monitoring. **Weaknesses** Requires terrestrial infrastructure and/or adequate consideration of options for data communication. Further research is also required for the development of robust behaviour algorithms.	Tags have broadly been proven in a research capacity although no reliable commercial system is available at this stage.

Platform	Details	Identification	Traceability – location resolution	Traceability – Attribute tracking	Strengths and weaknesses	Technical feasibility and likely time to market
Level 4 – Real-time location and activity monitoring	Future systems that incorporate advanced location and activity along with remote communication capabilities.	Identification linked to smart tag.	Absolute location through GNSS tracking data. Sub-paddock level. Proximity-based sensing based on relative position to other animals and/or places of interest.	As above but data is refined by the addition of higher resolution location data. The integration of location and activity data could help refine modelling for attribute detection. For example, specific disease detection might be enabled based on where an animal is well as what it is doing.	**Strengths** Ability to track absolute location to a fine resolution. Beneficial for disease tracing and/or tracing of close animal's contacts. Real-time location enables targeted interventions for example road closures in case of emergency disease outbreak. **Weaknesses** Significant investment and further technology development necessary. Further research is also required for the development of robust behaviour algorithms.	Several commercial entities working towards this solution. While technically feasible, long term testing of the retention and reliability of tags are required.

Platform	Details	Identification	Traceability – location resolution	Traceability – Attribute tracking	Strengths and weaknesses	Technical feasibility and likely time to market
Additional platform – Tissue sampling	Tissue sampling at tagging.	DNA-based.	N/A	Could be linked with on-animal sensors above to provide insights. Some attributes directly taken from tissue sample may prove valuable (e.g. genomic evaluation of populations, and early detection of residues or endemic disease).	**Strengths** Used to bolster the above systems. Allows for improved traceability along the entire supply chain, particularly post-slaughter and on to consumer. **Weaknesses** Would require significant investment and infrastructure for archiving and processing of samples. Implementation on property may be problematic.	Similar systems already in use in pork production value chains and provided by Allflex®.

Platform	Details	Identification	Traceability – location resolution	Traceability – Attribute tracking	Strengths and weaknesses	Technical feasibility and likely time to market
Additional platform – Satellite imagery for animal counting	Remote sensing for landscape level animal recognition and counting.	Counting of animal numbers. Individual level identification unlikely.	Paddock level counts of livestock populations.	Some behavioural traits may be enabled by repeat image analysis.	**Strengths** Could be used in regions where on-animal sensor application is impractical e.g. Northern Australia. **Weaknesses** Individual tracking unlikely with current imaging-based techniques. Unlikely to work with satellite based systems where tree cover and terrain issues prevail.	Requires further research

9. Application of the proposed systems

Having now reviewed available identification and traceability technologies and explored how these sensors might be integrated into future integrity systems, it is worthwhile understanding how they might be specifically applied. To do this, a basic description of the various functions of the current NLIS is provided (both current and perceived future functions), along with a general review of how new technologies might be applied to improve this system.

9.1 The current NLIS system

The current NLIS allows for traceability of livestock, including whole-of-life identification from first tagging to slaughter or export. The system enables monitoring of the location of animals at property level (PIC) and through this, an animals' association with others at a cohort level. In general, traceability systems, including the NLIS, are comprised of:

1. A method of identifying the individual animal or mob;
2. A method of identifying the physical location of said animal by use of property identification codes (PICs); and
3. A web-based database to collate and store the requisite information (Animal Health Australia 2015).

The identification technologies described in Section 7.1 are the candidates available to satisfy the first aspect. This is currently conducted by use of RFID ear tags and rumen boluses in cattle and RFID ear tags (voluntary for all states except Victoria) or visual ear tags in sheep and goats. Although these technologies have proven valuable, it is possible that other technologies identified in Section 7.1 could be used to improve the efficiency of the NLIS as standalone identification systems, or as part of an integrated system that exploits synergies into the traceability domain

Correspondingly, under the current system, fulfilment of traceability aspect requires producer input in the form of the NVD and facilitation of PIC transfer on the NLIS database. Again, similar to the above, the location tracking technologies described in Section 0 could be used to facilitate autonomous recording of livestock movement both within, between properties and to point of slaughter or export. This could be bolstered by attribute tracking technologies described in Section 0.

An additional requirement of the NLIS is adequate traceability of stock movement between properties (specifically, properties with different PICs). This is crucial for biosecurity purposes as management of infectious diseases may be further complicated by movement of animals. Under the current system, movement of animals between different properties must be recorded by the receiver of the cattle within two days of receiving the animals (NLIS 2016). This is achieved through use of the NLIS database.

While this process is reasonably efficient, there are some limitations to the current system. Firstly, PICs are managed by each state or territory, with some variation in the operational rules. For example, in NSW a single PIC may be held for multiple production sites (Petty 2020) meaning that animal movement between these sites does not need to be recorded. In addition, under the existing system the impetus for recording of stock movement relies on producer and/or processor themselves. This may impact compliance, particularly if there is no clear or obvious benefit from the declaration process (e.g. movement on or off leased land where there is not economic benefit to recording stock movement).

Use of automated identification and/or tracking technologies could help to facilitate autonomous recording of stock movement. This is possible from the Level 1 system, with each subsequent system providing finer-detail tracking methods. One limitation is that all animals would be required to have an electronic tag for automated recording of movement. This is limited in sheep and goat systems (other than Victoria) where RFID is not yet mandated. Furthermore, it is likely that improvements to the current RFID tag (e.g. development of a HF or UHF tag) would be necessary.

The following sections provide specific examples for application of the technologies for both current and future traceability functions. The current traceability functions are considered under two major areas: biosecurity and food safety. Future traceability functions include are aligned with industry sustainability and animal welfare. Rather than provide broad recommendations around how future integrity systems might impact on each function we have developed a case study approach. This provides the opportunity to explore key details relating to each future approach proposed in Section 8 and for consideration of how each would provide the requisite information for a specific NLIS function.

9.2 Current traceability functions

Biosecurity
Rapid detection and tracing of diseased animals is critical for adequate biosecurity response. Quick identification and intervention can increase the chance of disease control and containment and minimise the impact on the broader livestock industry and associated sectors. To ensure adequate detection, the livestock industry participates in both general and targeted surveillance for specific diseases.

General surveillance is used for the purposes of identifying changes in livestock disease profiles and involves: pre- and post-slaughter inspection at meat processors; inspection of animals at sale yards or similar; farm visits by private and government veterinarians; and results from laboratory testing (Animal Health Australia 2020).

In addition, there are specific biosecurity processes that must occur depending on the identified disease. Case study examples are described below.

Notifiable diseases
Notifiable diseases represent a significant threat to Australian livestock and must be reported to agricultural authorities. These diseases may be foreign or endemic and must be properly monitored to detect unusual events of animal sickness or mortality.

Foot and Mouth Disease (FMD)

FMD is an acute viral disease of domestic and wild ungulates. Clinical signs include the formation of fluid-filled blisters (called vesicles) in the mouth, nostrils, teats and skin around the hoofs. The route of infection is most commonly through inhalation of viral particles, although infection may also occur through minor abrasions on the feet, mouth, nose and udder. The incubation period is generally 14 days, although this may depend on the viral strain and the route of transmission. In general, cattle and pigs are more severely affected than sheep and goats (Animal Health Australia 2014). FMD is considered a high priority disease due to the serious impact an outbreak would have on the livestock industry and supporting sectors. In the case of a small outbreak, the estimated cost is approximately $6 billion over 10 years. If the outbreak was larger, this cost is estimated to be $52.5 billion over 10 years, with a loss of export market access costing a further $1 million to the supply chain each day (Xinova 2019).

Under the current NLIS system, if a producer suspects that an animal is showing symptoms of FMD, they must report this to their local veterinarian, state or territory department of primary industries or call the Emergency Animal Disease Watch Hotline. Once diagnosed, Australia's policy is to contain, control and eradicate FMD as quickly as possible. This requires adequate traceability of animals to ensure infected and potentially infected animals can be identified and quarantined quickly. For a full description of the FMD Disease Strategy, please see the AUSVETPLAN Disease Strategy (Animal Health Australia 2014). Application of the proposed future integrity systems for FMD control are explored in Table 9.

Bovine spongiform encephalopathy (BSE)

BSE is a type of transmissible spongiform encephalopathy (TSE), affecting the central nervous system of cattle and resulting in their death. The disease was first reported in the UK in 1986. Though the origin of BSE is unknown, the practice of feeding meat and bone meal to cattle has been implicated in its spread. For this reason, there is a national ban on the feeding of meat, meat and bone meal, poultry offal meal, feather meal, fishmeal or faecal material to ruminants (known as the 'Ruminant Feed Ban'). Australia has a BR Level 1 rating, meaning it is at a very low risk for BSE in cattle. Nevertheless, given the impacts that BSE detection would have on domestic and international market access, the disease is under constant extensive surveillance in Australia.

If a producer suspects that an animal is showing symptoms of BSE, they must report this to their local veterinarian, state or territory department of primary industries or call the Emergency Animal Disease Watch Hotline. Once BSE is diagnosed, the premises of the index case will be declared an infected premise (IP) and placed under quarantine. Following this, tracing will be undertaken establish the source of infection, danger to other herds and risk to the supply chain (including livestock products). Australia must also notify the World Organisation for Animal Health (OIE) within 24h of a confirmed case.

In addition to the above procedure, Australia also participates in targeted surveillance for BSE, managed under the National TSE Surveillance Project (NTSESP). The design of this is based on the guidance of the OIE *Terrestrial Animal Health Code*, 2015 Edition. Under these guidelines, Australia is required to implement a surveillance program that allows detection of at least one BSE case per 50,000 in the adult cattle population at a confidence level of 95%. This involves examination of clinically consistent animals throughout the supply chain, in addition to the examination of 300 brains from casualty stock each year. Histopathology is used as a screening test, followed by confirmatory testing at the CSIRO's Australian Animal Health Laboratory where required (Animal Health Australia 2020).

For a full description of the BSE Disease Strategy, please see the Australian Veterinary Emergency Plan (AUSVETPLAN) (Animal Health Australia 2012). Application of the proposed future integrity systems for BSE control are explored in Table 10.

Table 9 Application of each option for a future integrity system (see Table 8 for details) with specific reference to a FMD outbreak. Note that in most cases each higher-level platform can perform the function of the lower

Current system	**Level 1 – Transport tracking**	**Level 2 – Active medium or long-range RFID**	**Level 3 – Basic behavioural monitoring**	**Level 4 – Real-time location and activity monitoring**	**Platform additions**
Disease reported to a local veterinarian, state or territory department of primary industries or the Emergency Animal Disease Watch Hotline. Once diagnosed, trace back is required for a minimum of 14 days. Trace-forward is also applied for 14 days from the date of the first report. Tracing includes susceptible livestock and their products, vehicles and people (Animal Health Australia 2014).	Tracing is facilitated by entry/exit geolocations for livestock on vehicular transport. Improved historical cohort identification. Improves the fidelity of location data for disease tracing. Additional value is brought by having access to accurate transport route data showing which regions affected animals have passed through.	Level 1 benefits + Coarse positional tracking facilitates tracking of animal-animal contact locations for the previous 14 days.	Level 2 benefits + Attribute tracking could be used to detect aberrant behaviour which could be used to instigate inspections. This may assist with earlier FMD diagnosis. Data at a herd/flock or regional level might be integrated to detect disease state during outbreaks.	Level 3 benefits + Improved attribute tracking could detect clinical signs associated with FMD e.g. loss of appetite (by motion sensor), fever (by temperature sensor). Alerts are sent to the producer or biosecurity agent for targeted inspection. Improved location tracking for more precise recording of animal-animal contacts. The system could be developed in a scaled-up approach with sentinel animals within each herd/flock.	At any level, integration with existing feral species control programs (e.g. PestSmart, FeralScan) could help to identify the number of unmanaged 'carriers' in the region. From Level 2 onwards, positional tracking to a sub-paddock level could be integrated with environmental factors (e.g. wind direction) for risk modelling purposes. Satellite remote sensing of animal locations could prove valuable in a FMD response, particularly where large numbers of untagged animals occur.

Table 10 Application of each option for a future integrity system (see Table 8 for details) with specific reference to a BSE outbreak. Note that in most cases each higher-level platform can perform the function of the lower

Current system	Level 1 – Transport tracking	Level 2 – Active medium or long-range RFID	Level 3 – Basic behavioural monitoring	Level 4 – Real-time location and activity monitoring
Disease reported by producer. Once diagnosed, the premises of the index case is placed under quarantine. Tracing is undertaken to establish the source of infection, danger to other herds and risk to the supply chain Australia must notify the OIE within 24h. Australia also participates in targeted surveillance including examination of clinically consistent animals and 300 brains from casualty stock annually as per OIE recommendations (Animal Health Australia 2020).	More accurate tracing of the location of animals may enable improved identification of the source. Improved historical cohort identification. Improves the fidelity of location data for disease tracing.	Level 1 benefits + More accurate tracing of animal locations beyond transport locations may enable improved identification of the source. More accurate tracing of animal-animal interactions (cohorts) could enable improved traceability of other animals at higher risk of infection having been managed together <12 months of age.	Level 2 benefits + Attribute tracking could be used to detect general ill health of animals e.g. reduced activity. These animals might be targeted for testing. Earlier disease detection prior to processing will reduce exposure to contaminated body tissue.	Level 3 benefits + Improved attribute tracking could detect more specific clinical signs e.g. abnormal ear position or head carriage, behaviour change including aggression, social hierarchy changes. These animals might be targeted for testing. Identification of specific clinical signs is likely to be less valuable due to the progression of BSE over many months.

Anthrax

Anthrax is an infectious bacterial disease caused by *Bacillus anthracis*. Infection by the bacterium occurs by ingestion of spores or absorption through the skin. Once infected, the bacterium concentrates in the lymphoid tissue, where it produces a lethal toxin complex. This complex comprises of three factors which cause damage to capillary walls and interfere with blood clotting, causing oedema, shock and death. Once the bacterium and toxin complex reaches critical mass, they are released into the bloodstream and lead to rapid death. This is usually within 4 – 10 days of infection, although the OIE describes a longer incubation period of 20 days. In cattle, sheep and goats the disease is usually 'peracute' (i.e. very acute), meaning that death occurs suddenly, sometimes before clinical signs are observed. Anthrax is not considered contagious between live animals. Instead, the bacterial spores are often ingested after release from the carcase of the animal that has died. *B. anthracis* may also be transmitted mechanically by insect vectors (e.g. flies, ticks). It is also possible that scavenging animals (e.g. foxes) have a role in disease transmission (Animal Health Australia 2017).

Anthrax is uncommon in Australia and cases are only seen sporadically. Risk factors for the disease include areas with neutral to alkaline soils and those in flood prone areas near to waterways. Other risk factors include previous cases of the infection (even decades earlier), climatic conditions, drainage systems, topography and stocking density. Factors impacting spore viability on the soil surface include wind, rain, sunlight, acidity and dryness. In general, the first indication of anthrax in grazing animals is blood-stained discharge and failure of blood clotting. This is then confirmed by laboratory bacterial culture, microscopic examination or PCR testing.

For a full description of the Anthrax Disease Strategy, please see the AUSVETPLAN Disease Strategy (Animal Health Australia 2017). Application of the proposed future integrity systems for anthrax control are explored in Table 11.

Table 11 Application of each option for a future integrity system (see Table 8 for details) with specific reference to an anthrax outbreak. Note that in most cases each higher-level platform can perform the function of the lower

Current system	Level 1 – Transport tracking	Level 2 – Active medium or long-range RFID	Level 3 – Basic behavioural monitoring	Level 4 – Real-time location and activity monitoring	Platform additions
Disease reported by producer. Once confirmed, quarantine is imposed on the IP and all other premises where infection is suspected. Tracing is undertaken to determine the infection origin and to trace the movement of livestock on and off the premises. This includes any animals that left the IP within the 20 days before the presumptive index case. Targeted surveillance is also conducted on neighbouring properties.	More accurate monitoring of livestock locations might enable faster tracing in case of animals moved during outbreaks. Improved historical cohort identification. Improves the fidelity of location data for disease tracing.	Level 1 benefits + Coarse positional tracking facilitates tracking of animal-animal contact locations. Locations are provided at a sub-paddock level.	Level 2 benefits + Basic attribute tracking could be used to detect sudden mortality events potentially associated with anthrax. This could enable alerts for inspections by producer or biosecurity agent. Clusters of mortality events within properties or regions might provide stronger alert status.	Level 3 benefits + Fine scale location data associated with mortality events (GPS positions) could enable highly targeted treatment of carcases to prevent transmission or development of a soil harbour for later reinfection. Sentinel program might capture some more extensive outbreaks.	At any level, integration with existing feral species control programs (e.g. PestSmart, FeralScan) to identify the number of unmanaged ‘carriers’ in the region. From Level 2 onwards, positional tracking could be integrated with environmental factors (e.g. seasonal conditions, feed-base cover etc.) to identify other areas requiring surveillance. This would require dedicated modelling framework development.

Significant diseases are those diseases that are not notifiable, but still represent a significant welfare and economic threat to Australian livestock industries. These diseases are not strictly relevant to the NLIS system, although they have been included to illustrate other benefits associated with inclusion of tracking technologies in existing livestock systems. In addition, it is feasible that these applications could be used as "value-adding" for the NLIS system to encourage producer compliance.

Footrot

Footrot is a contagious bacterial disease in sheep and goats caused by *Dichelobacter nodosus*. This bacterium consists of several strains which influence the severity of disease (classified as either benign or virulent). Benign footrot causes mild lesions which usually resolve without treatment. Virulent footrot is a debilitating disease which significantly impacts wool growth and quality, as well as reducing animal growth rates, ewe fertility and general loss of economic value.

According to the NSW Department of Primary Industries (DPI), *D. nodosus* does not survive for more than 4 days in the environment, however it may persist in the feet of infected sheep for years, even during dry conditions. Infection by *D. nodosus* is generally through introduction of infected animals or exposure to infected land, however it will only spread when there is moderate ambient temperature and adequate moisture to make the feet susceptible (NSW DPI 2017). Virulent footrot is a notifiable disease in some states. Application of the proposed future integrity systems for footrot traceability are explored in Table 12.

Bovine ephemeral fever (BEF)

BEF, also known as Three Day Sickness, is a viral disease of cattle and buffalo. Clinical signs usually begin with a sudden onset fever, followed by reduced food or water intake, stringy discharge from the nose, drooling from the mouth, shivering and shifting lameness. Clinical signs are usually short-lived, with animals returning to good health in a few days. BEF is spread by biting insects (usually mosquitoes). As such, the distribution of insects due to climactic conditions influences the spread and time of disease. BEF can be prevented by vaccine use, although vaccination is usually dependent on the economic value of the animal or stage of management e.g. steers close to finishing weight may be vaccinated to prevent loss of condition, heavily pregnant cows may be vaccinated to prevent late-stage abortion (Kirkland and Bailey 2016).

Application of the proposed future integrity systems for BEF management are explored in Table 13.

Table 12 Application of each option for a future integrity system (see Table 8 for details) with specific reference to footrot. Note that in most cases each higher-level platform can perform the function of the lower

Current system	Level 1 – Transport tracking	Level 2 – Active medium or long-range RFID	Level 3 – Basic behavioural monitoring	Level 4 – Real-time location and activity monitoring	Platform additions
Virulent footrot must be declared in some states, including NSW, VIC and QLD. This requires reporting of any suspect cases to their local state or territory department of primary industries within one day of becoming aware of potential virulent footrot.	Tracing is facilitated by entry/exit geolocations for livestock on vehicular transport. Improved historical cohort identification. Improves the fidelity of location data for disease tracing.	Level 1 benefits + Coarse positional tracking facilitates tracking of animal-animal contact and/or contact to infected land Less valuable when only sentinel animals are tracked.	Level 2 benefits + Attribute tracking could be used to detect lameness. This has been demonstrated with accelerometer ear tags (Barwick et al. 2018a). These animals might be targeted for inspection.	Level 3 benefits + More detailed sensors could improve lameness detection Improved positional estimates from GNSS could help manage areas of potential exposure or contamination.	At any level, real-time disease spread forecasts could be used for predictive purposes. For example, integration of weather data to identify areas of high risk based on temperature and rainfall. Producers would be alerted during periods of high risk. However, this would require dedicated modelling framework development.

Table 13 Application of each option for a future integrity system (see Table 8 for details) with specific reference to a BEF. Note that in most cases each higher-level platform can perform the function of the lower

Current system	Level 1 – Transport tracking	Level 2 – Active medium or long-range RFID	Level 3 – Basic behavioural monitoring	Level 4 – Real-time location and activity monitoring	Platform additions
BEF is not currently tracked through the NLIS	The Level 1 system would not be significantly beneficial for BEF, other than for enabling more accurate tracking of infected animals that might have been transported to enable modelling of disease spread.	Level 1 benefits + Negligible benefit beyond more accurate tracing of locations of animals	Level 2 benefits + Attribute tracking by simple motion sensors could help identify animals of general ill health for targeted inspection	Level 3 benefits + Improved attribute tracking could detect specific clinical signs of BEF e.g. shifting lameness (from a motion sensor) or fever (from a temperature sensor).	At Levels 3 and 4, real-time disease spread forecasts could be used for predictive purposes. For example, weather data integration to model insect spread. The producer is alerted during high risk periods. This knowledge would allow for targeted vaccination of animals in high risk areas and/or aversion of co-morbidity factors e.g. mustering. This would require dedicated modelling framework development

9.3 Food safety

Food safety refers to the preservation of product integrity and safety standards across the supply chain. This is facilitated by full supply chain traceability. Introduction of new identification and tracking technologies for livestock traceability pre-farm gate could be used to bolster existing food safety measures. These are discussed in the following sections.

Residues

Accurate detection of residues in livestock products is important requirement of traceability systems to ensure continued access to export markets. Accurate livestock tracing can minimise these effects, and ensure violations are not repeated (AHA 2015a).

Residues from treatment applications

Residues can result from treatment applications (e.g. drench, vaccine) if animals are sent for processing without paying respect to sufficient withholding periods. They may also result from the use of undeclared HGPs. This is particularly important when supplying animals for HGP-free export markets.

Current surveillance methods require vendor declaration via use of the NVD. HGP may also be tested by ear palpation during processing, or by identification of a triangular ear punch or other markers indicative of possible HGP implant. Palpation must be carried out by competent staff to ensure compliance (Department of Agriculture Water and the Environment 2017). Application of the proposed future integrity systems for treatment residue tracing are explored in Table 14.

Chemical and metal residues

Residues may also result from access to chemically treated areas or from trace metals. To minimise risk of chemical residues, MLA’s on-farm Livestock Production Assurance (LPA) program is used to monitor livestock history and on-farm practices by use of NVDs and property risk assessment (Integrity Systems Company 2019). In the current NLIS system, detection of chemical residues relies on vendor declaration via use of the NVD. In addition, testing of sentinel animals may also occur when ERP status is declared. Non-LPA properties, even if they have a resolved ERP status, may also be targeted for testing (Queensland Government 2017). Application of the proposed future integrity systems for chemical residue tracing are explored in Table 15.

Table 14 Application of each option for a future integrity system (see Table 8 for details) with specific reference to treatment residues. Note that in most cases each higher-level platform can perform the function of the lower

Current system	Level 1 – Transport tracking	Level 2 – Active medium or long-range RFID	Level 3 – Basic behavioural monitoring	Level 4 – Real-time location and activity monitoring	Platform additions
Vendor declaration via the NVD. HGP may be identified by ear palpation, or by identification of a triangular ear punch or other markers indicative of possible HGP implant.	Improved historical cohort identification. If one animal is found with residue, this would flag all others in this cohort for testing. This would be beneficial for situations where groups of animals are delivered to property but later split into new management groups.	Level 1 benefits + Marginal improvement of cohort establishment.	Level 2 benefits + Use of activity and proximity data to identify movement of animals to the yards. This could be matched to input purchases (e.g. 20L drench purchased). This is less valuable when products are stored before use. This would also require the establishment of a separate system for handling data related to inputs. In some cases, it will be possible to directly measure the impact of a chemical treatment (e.g. Buffalo fly treatment can be detected using accelerometer ear tags).	Level 3 benefits + Cattle movement can be more accurately detected using absolute location tracking (e.g. GNSS) and matched with inputs validated through purchase records. Finer-scale location and behaviour data could also enable automated detection of some treatments (e.g. response to anthelmintic).	Development of an RFID-enabled drench applicator could help to facilitate direct records of treatments for specific animals. Tissue sampling at time of tagging may provide some base line data for treatments.

Table 15 Application of each option for a future integrity system (see Table 8 for details) with specific reference to chemical residues. Note that in most cases each higher-level platform can perform the function of the lower

Current system	Level 1 – Transport tracking	Level 2 – Active medium or long-range RFID	Level 3 – Basic behavioural monitoring	Level 4 – Real-time location and activity monitoring
Managed through the LPA program. Testing of sentinel animals may occur when ERP status is declared. Non-LPA properties, may also be targeted for testing (Queensland Government 2017).	Improved tracing by entry/exit geolocations for livestock on vehicular transport would enable detection of animals residing on high risk properties (e.g. ERP T3-T4 properties) Better historical cohort traceability to find other animals when one has tested positive.	Level 1 benefits + Coarse positional data could be matched with historical satellite imagery to identify co-location of livestock on old cropping country (potentially treated with Organochlorines).	Where chemical residues have a direct impact on animal health there is a possibility that monitoring behaviour may provide some indication of potential contamination.	Minimal benefit beyond Level 2 High resolution location data could be used to trace back to source of contamination at a sub-paddock scale. It is also feasible that high resolution location data could be used to detect time spent near high risk areas, e.g. old dips, chemical storage areas, rubbish dumps. A real-time alert could be developed for producers to provide a warning of animal access to these areas (dependent on base risk map development). Integrated tissue sampling could provide valuable baseline data on some contaminants

Product authenticity claims

Central to the NLIS system is management of Australia's reputation for supplying goods on both a domestic and global market. Although not currently a focus of the integrity systems, it is plausible that inclusion of measurable product authenticity claims could facilitate improved quality assurance programs. It is also feasible that this application could be used as "value-adding" for the current traceability system to encourage producer compliance. Relevant product authenticity claims may include pasture-fed beef, organic and Australian grown products (vs. fraudulent substitutes). Pasture-fed beef has been discussed briefly in this report as an example.

Pasture-fed beef

Certified Pasturefed is an assurance program managed by the Pasture fed Cattle Assurance System (PCAS) for the Cattle Council Australia. This program is underpinned by the PCAS standards which require identification and lifetime traceability of individuals, no confinement for the purposes of intensive feeding and minimum eating quality standards on-farm. There are also two optional modules within the standards to support claims for freedom from antibiotics and HGPs (Pasturefed Cattle Assurance System 2016).

Identification and tracking technologies could be used to facilitate the PCAS system and product authenticity claims more broadly. For example, from the Level 2 system, sensors could be used to validate that the intake of animals was predominantly from pasture. This would most easily be achieved through absolute localisation (i.e. from GNSS) as the physical location could be validated to be within a pasture (rather than near a feedlot). There is also scope that this could be achieved from strategic placement of readers for proximity detection (e.g. proximity to feedbunk/supplement feeding). A blue-sky option would involve the development of a rumen sensor that detects pH changes associated with concentrate feeding. While this would provide accurate information for data-driven certification, it is unlikely with existing technologies and would require significant investment.

9.4 Future traceability systems

This section provides an outline of an anticipated future state of the NLIS and broader integrity systems, including an exploration of what would be required to meet these needs.

Sustainability

To ensure future sustainability of the red meat industries, a commitment to sustainable environmental, economic and social factors are essential. The following sections have been developed around the four areas identified in the Australian Beef Sustainability Framework (Sustainable Australian Beef 2017).

Environmental stewardship

The data made available through the proposed traceability systems could provide valuable insights for the industry as a whole as well as for individual producers. For example, improved understanding of the exact location of livestock at a property-level, along with marginal increases in property-level data, could enable the calculation of real-time property or regional stocking rates. This could then be compared to district recommendations to identify impending overgrazing issues. More specific location data from livestock could be also integrated with remote sensing imagery to quantify areas of patch overgrazing or where ground cover is reduced by reasons other than livestock (i.e. by native herbivores). Application of the proposed future integrity systems for environmental sustainability are shown in Table 16.

Table 16 Application of each option for a future integrity system (see Table 8 for details) with specific reference to environmental stewardship. Note that in most cases each higher-level platform can perform the function of the lower

Level 1 – Transport tracking	Level 2 – Active medium or long-range RFID	Level 3 – Basic behavioural monitoring	Level 4 – Real-time location and activity monitoring	Platform additions
Improved property level location data could enable generation of real-time stocking rate estimations for comparison to regional recommendations. This data could be used to demonstrate stewardship or enable targeted extension activities to improve individual producer feed base management	Incremental benefits from improved location accuracy	Behavioural monitoring of animals can provide information on the feed base which could be used to validate optimal grazing management strategies aimed at improving landscape sustainability.	Location data could be matched with paddock data to provide highly accurate estimates of stocking rate for comparison with carrying capacity. Location data could be used to monitor and alert to patch overgrazing. Location data could be used to validate areas of property set aside for conservation outcomes where no grazing occurs. Areas showing little or no grazing activity could be proactively identified for transition into conservation or protection with little impact on production.	The integration of remote sensing data with accurate livestock location and activity data could provide significant insights, particularly if undertaken at a national level.

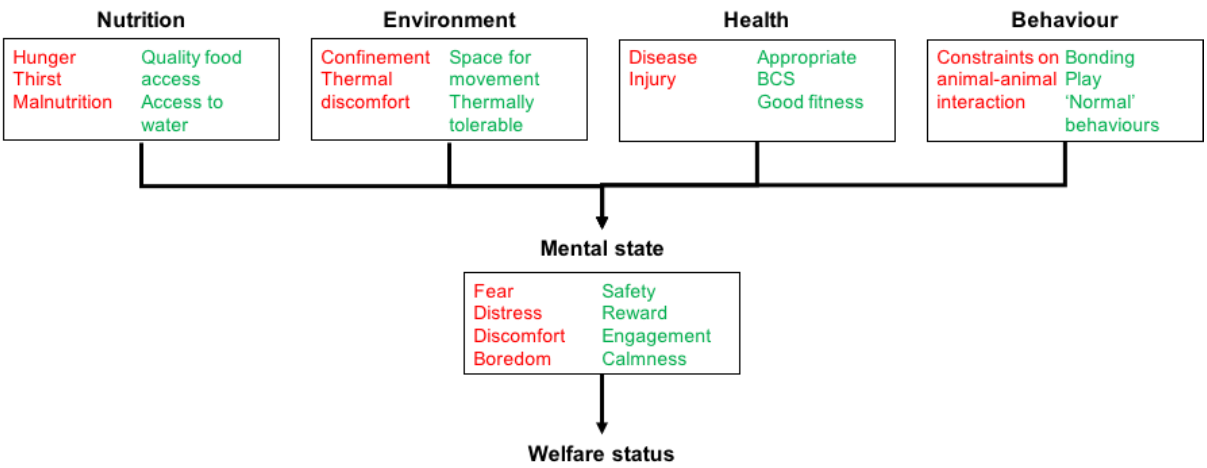
9.5 Animal welfare

The maintenance of high animal welfare standards is an important issue for the red meat industry. Poor animal welfare has obvious implications for the animal itself, including pain and suffering. Furthermore, poor animal welfare has economic and productivity implications (Dawkins 2017), and may impact consumer perception of the industry. Future traceability platforms provide the opportunity for benchmarking of welfare practices but also offer a means of validating welfare claims for marketing purposes.

One of the key issues that needs to be explored is how sensor systems can be applied to measure animal welfare. This is not a straightforward or simple concept. Animal welfare monitoring is usually conducted through welfare guidelines; e.g. the World Organisation for Animal Health's 'General Principles for the Welfare of Animals in Livestock Production Systems' (Fraser et al. 2013) and the European Union's 'Welfare Quality® Project' (Welfare Quality Network 2018). These programs are broadly developed through integration of various welfare paradigms and frameworks, including the Five Freedoms and the Five Domains Model and three conceptual frameworks; 'biological functioning', 'affective states', 'natural living' (Hemsworth et al. 2015). For simplicity, only the Five Domains Model will be discussed here.

The Five Domains Model encompasses four physical/functional domains (Nutrition, Environment, Health and Behaviour) and one mental domain (Mental state). In this system, both positive and negative aspects of the first four domains are considered and assessed, after which their anticipated effect on the fifth 'mental' domain can be carefully inferred (Mellor and Beausoleil 2015). Figure 4 provides an illustrative example of the Five Domains Model.

Figure 4 An illustrative description of the Five Domains Model for welfare assessment



Animal tracking technologies offer the potential to improve current animal welfare standards through continuous monitoring of animals in their environment (Fogarty et al. 2019). Application of the proposed future integrity systems for the monitoring of animal welfare are shown in Table 17.

Table 17 Application of each option for a future integrity system (see Table 8 for details) with specific reference to animal welfare monitoring. Note that in most cases each higher-level platform can perform the function of the lower

Level 1 – Transport tracking	Level 2 – Active medium or long-range RFID	Level 3 – Basic behavioural monitoring	Level 4 – Real-time location and activity monitoring	Platform additions
Improved vehicular tracking could be used track time spent travelling and ensure improved monitoring of animal welfare during this time. **Nutrition:** time spent without food/water **Environment:** time spent in a confined vehicle. This would be particularly valuable during periods of high temperatures. **Health:** improved tracking for disease tracing **Behaviour:** impacts 'normal' livestock behaviour. Improved and constraints on animal-animal interaction **Mental state:** inferred impact on fear, distress and comfort levels	Level 1 benefits + Coarse positional data to improve location tracking of animals. Less valuable when only sentinel animals are tracked. **Nutrition:** access to quality pasture. Would require linkage to base maps with nutritional information (e.g. NDVI) **Environment:** proximity to shelter. Only possible if readers are located at sheltered areas **Health:** access to important resources e.g. water. Only possible if readers are located at water points. **Behaviour:** monitoring of 'normal' livestock behaviour including animal-animal interaction **Mental state:** inferred impact on fear, distress and comfort levels	Level 2 benefits + Attribute tracking by simple motion sensors. **Nutrition:** monitoring of grazing behaviour **Environment:** detection of time spent resting **Health:** identification of general ill health for targeted inspection **Behaviour:** performance of 'normal' diurnal activities and social behaviour **Mental state:** inferred impact on mental state e.g. calmness, social reward	Level 3 benefits + Improved attribute tracking by motion sensors and integration with absolute location by GNSS. **Nutrition:** matching of grazing behaviour to location of the animals **Environment:** access and use of shelter areas **Health:** identification of specific diseases for targeted inspection **Behaviour:** improved behaviour monitoring **Mental state:** inferred impact on mental state	At any level, inclusion of a HR monitor would have significant benefits for monitoring the animal's physiological state. In addition, HR can be used as a measure of mental stress. This would require significant investment and further research to determine the most appropriate form factor.

Economic resilience

To ensure that Australia's red meat industry continues to thrive, it is important to consider sustainability from an economic perspective. This is important for both lasting endurance and continued industry improvement [e.g. to reach the National Farmers Federation goal to make agriculture Australia's next $100 billion industry by 2030 (National Farmers Federation 2020)]. Key to this is the maintenance and continued improvement of the integrity systems that underpin our international reputation and export market access (Sustainable Australian Beef 2017). The impact of real-time tracking of livestock has already been reported by Trotter et al. (2018). Briefly, the authors state that remote monitoring of location and behaviour state of livestock (LBS) would result in a 6.8% increase in revenue and 3.8% cost saving in pastoral beef systems. Benefits were similar for beef operations in the high rainfall/sheep-wheat zone, including a 6.0% increase in revenue and 4.7% cost saving. The majority of these benefits were reported as incremental improvements in productivity, with cumulative effects on the farm's bottom line. Modelling of this potential benefit over a 10-year period was reported between $280 and $808 million for the beef industry and between $204 and $501 million for sheep. See Trotter et al. (2018) for a detailed report.

People and the community

According to the Australian Beef Sustainability Framework, a safe and capable workforce is crucial for industry sustainability (Sustainable Australian Beef 2017). This includes building of workforce capacity and ensuring high levels of occupational safety. Use of automated tracking technologies such as those outlined in this report have direct benefits for the industry driving productivity, profitability and efficiency by allowing producers to make evidence-based decisions in a timely manner. This is facilitated through the automated collection of data, facilitating data-driven change in the industry; an important functionality of future integrity systems. However, essential to the success of the adoption of this technology and its technical feasibility is the agricultural workforce having the skills and knowledge to use this information. In addition to this, an increased use of technology in the industry will also likely encourage more workers into the sector which would assist with the current and future projected skills shortage (Wu et al. 2019).

Research and development is needed to ensure current and future generation agricultural workforce have the capacity to make the most out of the data collected by a future integrity systems. An example of project which aims to increase the knowledge and skills of high school students in emerging agricultural technology, specifically the tools and systems which provide animal location and behaviour data is GPS Cows. This project is a collaboration between CQUniversity, the NSW Department of Education and the Queensland Government (Cosby et al. 2019).

10. Case studies for the application of the proposed systems

Three case study topics were chosen to evaluate in greater depth from current (biosecurity and food safety) and future (sustainability) integrity system functions. Industry consultations were undertaken to elucidate any specific issues perceived by key stakeholders if the application of on-animal sensors or 'smart tags' was to occur in a future integrity system to address a Foot and Mouth Disease (FMD) outbreak, product authenticity claims for the Pasture-fed Cattle Assurance System (PCAS) and animal welfare issues through the fit-to-load process. The scope of these case studies was limited to level 1 and 4 of the proposed system as exploring all potential options of technology development and future traceability needs would be unnecessary. Each case study identifies the key activities that occur and the current weakness in the system in terms of traceability. The potential of a level 1 and 4 system to alleviate these issues is then outlined followed by specific comments from industry consultations reported in Appendix C. The points of intervention where a future integrity system could assist to detect and respond to an FMD outbreak is presented in a table as the process follows a specific chain of events. The PCAS and fit-to-load case studies are presented. Participant commentary of issues around acceptance of a future integrity system incorporating 'smart tags' is then discussed.

The potential value of a 'smart tag' to improve on-farm production was highlighted by participants as vital, however exploring this was beyond the scope of this research. Participants were told to assume that a 'smart tag' used for the purposes of a future integrity system would work, be affordable and compulsory to adopt (similar to the current EID NLIS tag for cattle, and sheep and goats in Victoria).

A summary of the key findings from each case study are presented below. A more detailed analysis of the results of each case study can be found in Appendix C.

10.1 Foot and Mouth Disease

Under the current NLIS system, if a producer suspects that an animal is showing clinical signs of FMD, they must report this to their local veterinarian, state or territory department of primary industries, or call the Emergency Animal Disease Watch Hotline. Once diagnosed, Australia's policy is to contain, control and eradicate FMD as quickly as possible. At the time of diagnosis, movement restrictions will be put in place with a national standstill of all susceptible animals implemented immediately and lasting at least 72 hours. During this time, tracing of animals, people and product movements would occur (AHA, 2019; Buetre et al., 2013).

Table 18 shows a summary of the key aspects of how FMD is currently managed and where sensor systems might play a role to improve detection and response. Further details and explanations of the various aspects of this table, along with detailed discussion relating key points provided by participants in the interview process are available in Appendix C.

Table 18: Chain of events where a future integrity system could assist in the detection and response to an FMD outbreak

On-farm detection			
What currently happens?	**Weakness of current system**	**Could a Level 1 System help? How?**	**Could a Level 4 System help? How?**
Producer observes suspect animals	In remote areas producer observations are limited. Recognition of disease by producers is limited Small-holders have poor diagnostic skills	A level 1 system would have no benefit in detecting FMD	Individual animal symptoms might be detected but could be similar to other disease Herd scale symptoms (rapid infection of multiple animals) would provide alerts Alerts would trigger inspection requests for producers
Producer reports suspected case to local agent	Reluctance to report disease by producers an issue Small-holders fail to report as they do not grasp seriousness of situation		Automated direct reporting of herd scale infections Reporting of producer requests to inspect Fail to report triggers agency inspection
Local or government veterinarian inspects animals and collects samples	Agency inspection delayed by producer detection and reporting process		Veterinarian directed to specific animals, paddocks or herd on property for inspection or sampling

Response to FMD outbreak			
What currently happens?	**Weakness of current system**	**Could a Level 1 System help? How?**	**Could a Level 4 System help? How?**
Animal location and tracking of cohorts undertaken	Inaccuracy in location of animals at a property level. Current PIC system has limitations as multiple properties can be registered against single PIC.	Specific vehicle entry/ points of livestock known refining the accuracy of likely animal location A historical examination of likely small holder entry/exit points could prioritise targeted inspections.	Specific real-time location of animals enables targeted inspection.
	Cohort establishment based on PIC and not actual animal-animal interactions	Cohort identification improved due to colocation on transport vehicles and entry/exit points	Specific animal-animal interactions quantified to provide risk rating for likelihood of transmission.
	No information on actual location of animals within a property	No benefit of a Level 1 system	Real-time location data provides within property location for rapid targeted inspection.
Restricted areas imposed to reduce transmission. Inspections commenced.	Not all animals within the restricted area may be known. Full inspection prioritisation is unknown (outside wind direction) but unlikely to be based on detailed knowledge of animal locations and symptoms.	More accurate location of animals exiting transport vehicles may provide refined search criteria for inspectors	Real-time location of animals enables prioritisation for inspections Increased detection algorithm sensitivity during outbreaks directs rapid response inspections
	Disease spread modelling based on wind direction and animal locations at a property level.	Modelling of disease spread along transport routes improved by specific location data.	Exact location of animals enables improved modelling as specific distance of individuals (with sensor-based infection status) along with transmission factors (e.g. wind/speed direction) provide refined inputs.
	Communication in the event of lock-down includes direct calling of PIC contacts, door to door, local media etc.	A vehicle-based animal tracking system could be developed that integrates alerts to transporters	Sensor systems could be developed that provide simple warning status of events (e.g. flashing red LEDs) to provide an indicator to animal managers of a situation
Managing vehicle and animal movement within a	No tracking of vehicles or animals enabled through current system	Attempts to move animals on system equipped vehicles results in immediate notification to authorities	Yarding of animals and any sort of unauthorised movements alerted to authorities

restricted area		Attempts to move empty livestock transport vehicles results in immediate notification to authorities	Empty vehicle tracking not enabled by this system unless all transport vehicles also fitted with monitoring systems

10.2 Pasture-fed Cattle Assurance System (PCAS)

PCAS has been chosen as the focus of this case study as the criteria producers must satisfy are freely available. To gain PCAS certification, producers are required to prove that they operate a grass-fed production system, comply with the PCAS requirements and maintain accurate records. Producers can determine whether their production system complies by conducting an online self-audit. The self-audit requires the producer to answer questions relating to their production system and provides an indication of whether the enterprise conforms to the PCAS standards. The findings of this case study highlight how 'smart tags' can be used in a future integrity system for product authenticity claims. The main areas of the production system which were examined as part of the PCAS case study relate to requirements for animal identification, nutrition, health and welfare. Whilst PCAS also has many criteria related to assembly, sale and transport of livestock, these standards are covered in the fit-to-load case study to avoid repetition.

Table 19 shows a summary of the key activities that occur within PCAS, how they are currently managed and where sensor systems might play a role to streamline and provide objective data for certification. Further details and explanations of the various aspects of this table, along with detailed discussion relating key points provided by participants in the interview process are available in Appendix C.

Table 19: Key activities with PCAS where a future integrity system could assist with the certification process.

Pasture-fed Cattle Assurance System (PCAS)			
Key Activity	**Weakness of current system**	**Could a Level 1 System help? How?**	**Could a Level 4 System help? How?**
Lifetime identification, location and time in confinement of individual animals	It relies on NLIS/visual tag and farm records to enable eligible or ineligible animals to be identified	A Level 1 System could provide individual identification of animals as they depart from the farm and arrive at another destination. It will not assist with lifetime identification nor, real-time location of animals to determine time spent in confinement on-farm.	Provision of real-time location and accelerometer data may be able to provide objective information to certify that animals have been confined and transported as per PCAS guidelines. A 'smart tag' may have retention issues and therefore lifetime traceability may be compromised.
Livestock nutrition	It relies on self-reporting of producers to confirm animals have had access open pasture, being supplemented with only approved feeds, provided with a rising plane of nutrition and restrictions are imposed around grazing of cereal grain crops met.	No benefit of a Level 1 system	Provision of real-time location and accelerometer data, through the development of robust algorithms, may be able to identify ineligible animals which have not met nutrition requirements. Additionally, the location of animals could be incorporated with other data streams such as satellite imagery could be incorporated to verify claims related to access to and quality of pasture.
Animal health and welfare monitoring	It relies on self-reporting of producers to confirm lifetime animal health and welfare status.	No benefit of a Level 1 system	Provision of real-time location and accelerometer data, through the development of robust algorithms, may be able to identify ineligible animals which have been sick, injured or had their welfare status compromised.

On-farm audits	Audits are time consuming, costly and rely on producers to self-report.	No benefit of a Level 1 system	Provision of real-time location and accelerometer data could identify individual eligible and ineligible animals based on certification criteria. Furthermore, audits may not need to be conducted on-farm and instead could conducted autonomously from a distance.

10.3 Fit-to-Load

The Australian Animal Welfare Standards and Guidelines - Land Transport of Livestock (the 'Welfare Standards') provide the standards and guidelines for all people involved in livestock transport and form the basis for consistent legislation throughout Australia. One of the most important aspects of 'fit to load' is that the 'person in charge', that is the person responsible for the welfare of all livestock under their control changes at different points throughout the journey. There are a number of issues associated with transporting livestock that may lead to breaches in compliance or disagreements between the consignor, transporter and receiver of livestock arising. These can include losses in opportunity to sell an animal, disagreements due to differences in weights between time of sale and unloading, and failures to lodge livestock movements.

The findings of this case study highlight how 'smart tags' can be used in a future integrity system to verify animal welfare prior, during and after transport. The key activities associated with livestock transport were examined as part of the fit-to-load case study. These relate to the assembly, loading, transport and unloading of livestock.

Table 20 shows a summary of the key stages that occur during the transportation of livestock, how they are currently managed and where sensor systems might play a role to streamline and provide objective data to key stakeholders. Further details and explanations of the various aspects of this table, along with detailed discussion relating key points provided by participants in the interview process are available in Appendix C.

Table 20: Key activities during the transportation of livestock where a future integrity system could assist.

Fit-to-Load			
Key Activity	**Weakness of current system**	**Could a Level 1 System help? How?**	**Could a Level 4 System help? How?**
Assembly of livestock	It relies on the honesty of the consignor to adhere to the guidelines regarding the assembly of livestock. If transporters believe animals have not being properly prepared, the absence of an objective measure does not allow them to confidently communicate this to the consignor	No benefit of a Level 1 system	Real-time location data can corroborate the consignor's story and confirm the length of time animals have been in yards prior to loading. An accelerometer-based sensor system could be developed that provide a simple warning to consignors and transporters about animal activity, which could be used to determine if they are 'settled' and ready to load. This shifts from been process driven to outcome based.
Loading at property	It relies on the subjective visual assessment by an individual, and for the consignor and transporter to both agree, to determine whether animals are fit to load. Disagreements over whether animals are fit to load, whilst not common are of a huge concern because of the legal implications for the transporter.	No benefit of a Level 1 system	Provision of real-time location and accelerometer data may be able to identify any animals which are potentially sick or injured and therefore not fit to load.
Journey of livestock including spelling periods & unloading at destination	There is a lack of objective information available to determine what occurs whilst livestock are transported. This can lead to disagreements between consignors and transporters if animal welfare is comprised.	A vehicle-based animal tracking system could assist with determining arrivals departure and spelling times of animals but provides no quantification of the journey and how that may have contributed to poor animal welfare or carcasses grading poorly.	The provision of real-time location and accelerometer data could be used to develop an alert system if animal welfare is compromised. Additionally, an objective record of time spent travelling and being spelled would be created.

11. Economic value of implementing a future integrity system that provides real-time location, behaviour, and state information for livestock

An economic analysis of the value of on-animal sensors in a farm management context has previously been explored. Modelling suggests total accumulated benefits of between $280 million (minimum) and $808 million (maximum) for the beef industry, and between $204 million (minimum) to $501 million (maximum) for the sheep industry over a 10 year period (Trotter et al., 2018). However, these figures do not include the economic value that might be brought about by applying sensor data to the various functions of the Integrity System. The data for investigating the potential economic impact of implementing (or the opportunity cost of not implementing) a future integrity system is not readily available. The MISP2020 is the key industry report which does provide some suggested baseline values that are used as the basis for the discussion below.

Two of the three case studies explored in this report (FMD and Fit-to-load) fall within the 'Consumer and Community Support' and the 'Welfare of Animals Within our Care' pillars. The fit-to-load case study can be specifically related to "continuous improvement of animal welfare" and FMD falls within the "minimising risk and impact of emergency disease" imperative. The PCAS case study relates to the supply chain efficiency and integrity component of the framework and specifically links to "Guaranteeing product and systems integrity" priority.

The primary economic value related to the Fit to load and FMD case studies is suggested to be a component of a total down-side risk of approximately $3.3 billion. Down-side risks include loss of consumer confidence due to adverse welfare outcomes and the impacts of disease. The challenge remains distinguishing between the value that might be apportioned across these quite different applications of an integrity system enabled with real-time location behaviour and state information. There is significant community interest in the welfare of animals and a clear potential benefit to be derived from having objective data to validate the treatment of animals, as well as inform improvements to current systems. A future integrity system that uses real-time location behaviour and state information could provide significant value in reducing this $3.3b down-side risk.

The report by Trotter et al. (2018) primarily explored the economic value of real-time location, behaviour and state data for producers seeking to improve on-farm management. However, a preliminary exploration of data relating to the improved management of welfare and biosecurity was undertaken. Using data from Buetre et al. (2013) and Hafi et al. (2015), Acil Allen developed a dataset (see Table 53 in Trotter et al. (2018)) that compared the annualised (and risk weighted) costs of a minor outbreak of FMD ($0.06 billion in Victoria and $0.06 billion in Qld) with a major outbreak ($0.52 billion). Given the information provided from the consultations from the FMD case study it is feasible that the development of a next-generation integrity system capable of collecting real-time location, behaviour and state data could prevent a small-scale outbreak from developing into a major one and thus an FMD event prevention cost saving of $0.46 billion per year ($0.52b - $0.06b) could be attributed at least in part to this sort of technological development.

The down-side risk related to the PCAS study which falls within the "Guaranteeing product and systems integrity" is valued at approximately $1.4 billion. Obviously, the grass-fed market remains only a small proportion of the total red-meat industry, and therefore only a minor percentage of this value can be directly linked to the benefits that real-time sensor systems might bring to this particular application. However, a number of other product authenticity claims would certainly be impacted by the development of an integrity systems which includes real-time location, behaviours and state information.

Conclusion

While some value propositions can be inferentially drawn from existing studies, there is no clear line of sight to the potential economic benefits that might be achieved through the development of an integrity system that provides real-time location, behaviour and state information. In particular the base line benefit values that are provided by the current Integrity System applications are not clearly presented in any literature and these are required to enable the calculation of any improvements that might be made by new and emerging technologies.

12. Participant commentary of issues around acceptance of a future integrity system

Participants were asked about their perception of the issues that may be faced if a future integrity system utilising animal location and behaviour state data was implemented. Whilst it is anticipated that a 'smart tag' would also bring benefits in terms of productivity and efficiency to the red meat industry, participants were asked to reflect on a scenario where adoption was compulsory, the technology was affordable and reliable.

It was recognised by many participants that acceptance across the industry of a 'smart tag' for integrity purposes will be difficult to achieve. Producer acceptance was recognised as the number one driver of the success for a future traceability system and how to achieve this is essential, '*farmers may be different from the rest of the population, but you talk implementing technology, and the first thing they do is put their stop sign up*.' Connectivity was also mentioned as a key barrier to adoption of any digital system. One participant also expressed that it is important to ensure any new system is implemented properly noting there are still many issues with the eNVD portal. It was hypothesised by one participant that unless the 'smart tag' was made mandatory for integrity purposes, adoption would be low using the LPA as an example, '*but it was voluntary. Nobody did it. It had to become mandatory*.'

12.1 Industry sustainability

One participant saw the information derived from a 'smart tag' to provide individual producers and the industry as a whole as a way to improve practices, '…and then if that doesn't match up with what the sensor tells us, how can we make it better?' This will assist with maintaining the reputation of Australia's red meat industry and establish individual producers as leaders in the sector. Whilst some producers strive to achieve premium prices for their product and will implement tools and technologies to help them do this, others are not interested. 'It amazes me the amount of people that are happy to just do what we do and... not want to drive things… [t]here's so much good stuff out there already that's not taken up. It never will be.' However, another participant recognised despite this segment of the industry, '…you can't hold the top 10-20% of the industry that's progressive back…and hopefully, the rest will catch up.' This participant did recognise the need to engage the bottom 10% of producers to try and support them to adopt new technologies such as a 'smart tag' as they 'can cause you a hell of a lot of trouble in terms of integrity of product.'

12.2 Value proposition

Although a 'smart tag' has the potential to assist with the detection and response to a disease outbreak such as FMD, it was recognised as they are such rare events, albeit with devastating economic and social consequences, it is unlikely the benefits provided would outweigh the cost of the technology. This highlights the need for any 'smart tag' to possess the ability to provide information on numerous aspects of animal behaviour, 'I think you would find the cost-benefit…is not going to be particularly high, so you'd probably want to look at anchoring it to some other day-to-day benefits.' Another participant reiterated the importance of a cost-benefit analysis being undertaken to clearly demonstrate the value proposition of 'smart tag' technology, 'I think if you could demonstrate that day-to-day boost to productivity and profitability…then I think it would be highly attractive…but it doesn't just have to have a positive benefit-cost, it has to actually give a higher rate of return than something else that you could readily put your money into.'

The system was seen to not only have potential benefits for saleyards and processors, however it was emphasised the importance that the value proposition is obtained by the producer, not just other stakeholders across the supply chain, 'you don't want it to just be meatworks as the only ones that benefit. You want back along the chain a bit more as well.' This was reiterated by another participant that felt that 'the value … gets absorbed at the processing [stage]…' However, for a future traceability system to work, adoption and value proposition is needed at all levels of the red meat supply chain.

12.3 Building capacity of users

Participants emphasised the need for any new system to be intuitive and user friendly, with one person noting, 'I think when it becomes something that you need to go to a training course for, it would be very difficult to get take-up for that…you didn't go to a course to learn how to use Facebook… I think they are the applications that become successful because there's very little barrier to interacting with it.' To maximise uptake, the general consensus was the simpler the system, the better, with the current NLIS database identified as an example of a complex and therefore underutilised tool.

Age was not perceived as barrier to the use of 'smart tag' technology by all participants, noting there are many older producers who are interested in adopting innovations, and younger ones who are not. However, one participant recognised that there is a segment of older users who are not particularly tech savvy and this is a barrier to compliance with the current system, 'I'm aware that there's plenty of producers out there that don't want to log in to the NLIS database and make the movements. They'll get someone else to do it, or they just don't do it all.' One participant identified that there are still people in the industry who have not used the NLIS database and still rely on others to make movements on their behalf (e.g. agents) especially smaller landholders who do not need to use the system frequently.

One participant reiterated the diversity of familiarity and digital skills across the red meat supply chain and the need for various means to build capacity within the industry to cater for different learning styles and background knowledge. Another participant recognised that people embrace technology differently, and found the agricultural industry was polarised in its view, with some believing there is no need to change what they have been doing and others as, 'the more modern farmer who's looking for that…competitive advantage trying to improve the operation.'

Using the information from the 'smart tag' frequently and receiving on the job training was seen as essential. If it was something that was used every few months, it was unlikely users would retain knowledge of how to best make use of the system. Some participants hypothesised that training would be needed in the form of workshops so that users could learn how to use any software associated with a 'smart tag.' They would want to know how to generate reports, gain useful data and any tips and tricks to make the most out of the system. These workshops would also clearly identify the benefits and opportunities that adoption of 'smart tags' would bring to their enterprise. A partnership between industry bodies and commercial providers of the technology was seen as appropriate to facilitate any workshops, as it was in their interest to see the adoption of 'smart tags' accelerated.

12.4 Information versus data

The majority of participants said that they were not interested in the data the system can collect, but rather the information it can provide. The need for a system to provide alerts to a producer when action was needed, as opposed to having to interpret data collected was reported by one participant as essential. Additionally, it was highlighted that if a person who is not the producer (e.g. agent, vet, processor) receives alerts from numerous enterprises, this would cause an information overload and lead to important issues possibly being missed. It was suggested that if information was to be shared across the supply chain, the producer would receive it all, and certain sections would be accessible by other parties.

12.5 Data ownership

It is important that consideration is given to data sharing and ownership between stakeholders at all levels to establish trust. It cannot be assumed that this trust between producers, government and industry bodies currently exists and work is needed to develop this.

12.6 Additional technology required to support adoption

Another concern raised by a participant was that producers with only a small herd might find the technology to readers the 'smart tags' a significant expense in addition to the tags themselves. Participants stated that some producers are comfortable with visual tags and how the system currently works and do not understand why they should outlay money for technology for which they do not perceive a benefit. Participants agreed that readers in trucks (Level 1 System) were a good idea and would help improve compliance and reduce costs for producers. But there were concerns about putting the responsibility on truck drivers. However, this system would allow trucking companies to offer a better service in that they would be doing the transfer and lodgement of livestock movements.

12.7 Ear tag form factor

One participant questioned the use of an ear tag in a future system over a bolus saying, '*I'm actually a proponent of boluses over ear tags, because I spent a lot of time in Northern Australia … [because of] the retention rate-- especially when [cattle are] only seen once a year.'* They did however note the issues with boluses identified in the milestone 1 report, '*but then of course you've got your problems of transmission through the animal and helping her to recharge it*.'

Another participant also noted past and present issues with ear tags including retention and durability. This highlights the continued need for research and development into the trialling of 'smart tag' technology under commercial conditions over extended periods of time to provide confidence to across the sector.

12.8 Building the capacity of the trucking industry to use technology

Through consultation with participants from the livestock transport sector, lessons were learnt about the role technology now plays in their day to day activities for both human and animal outcomes. Emphasis was made on how they inducted their staff and provided refresher training, both something that the red meat sector could learn from. Additionally, they spoke of how they introduced technology, such as Seeing Machines, to their drivers.

Participants from large transport companies outlined the comprehensive training and induction processes drivers undertake. They reported that induction processes vary in length depending on the previous experience of the driver but involve both theory and practical sections. Companies that are TruckSafe Animal Welfare accredited are required to provide training to their staff that is 'focused on humane transportation of the stock, on how to prevent disease, stress and contamination problems when moving them, on making sure the 'paddock to plate' traceability for livestock is supported during the journey and on the eating quality and safety of the final meat product' (TruckSafe, 2020). A refresher is required for staff every three years, however some participants who were consulted provide training annually. It was articulated by one participant that it was important to them that their staff have a knowledge of the agricultural industry, '*we're livestock carriers, so this is our trade, and we need to be at the front. We need to know what our trade is*.'

The transport industry provided an enormous insight into how they have successfully introduced their workforce to a suite of truck and driver fatigue technology, '*it's all about driver engagement and onboarding, and taking them through that journey, and coaching them through it*…' They outlined the need to get the buy-in and feedback from their drivers using the technology to ensure they understand how it works and the benefits that follow. One of the key findings they had whilst undertaking this process was the importance of using simple language (backed by a university study) when explaining the technology, '…use simple words; instead of using data, use information. It's the information that we receive'.

Participants recognised that although some of their more senior staff members are not competent in the use of computers, all could use apps and social media on a smartphone, 'I think most people can adapt to modern technology pretty well these days. You look at the iPhones and the iPads and all that now, GPS's, and I don't think it'll take too much for people to work out to be honest.' However, the majority of the technology the trucking industry has implemented does not require users to change their behaviour, 'that's the beauty about the 'Seeing Machines', for example, is that you just drive. You don't have to log on. It's a non-wearable. It's a non-interactive...It's a permanent fixture' and is designed to save lives. Additionally, as it is the company that has expended the resources (albeit at a big expense) to purchase this technology, it is unsurprising that it appears there has been little push back from drivers. This is different to the barriers faced by producers in adopting 'smart tag' technology as individual enterprises will be required to cover the cost for an item they don't necessarily see a clear value proposition for yet. Participants in the trucking sector reiterated the difficulty in balancing animal welfare, driver fatigue and the relevant laws, with technology being implemented in larger companies to address some of these challenges.

13. Conclusions and recommendations

13.1 Conclusions

This research has demonstrated the potential for integration of novel identification and tracking technologies to improve Australia's red meat traceability and integrity systems. A number of technologies, both within and outside of the livestock industry, were identified as having potential value. On-animal sensor systems appear to be the most appropriate for future application, based on their established acceptance within the industry and ease of deployment.

To illustrate how these technologies may be incorporated into future integrity systems, four approaches, each with increasing complexity, were detailed and discussed, including a critical evaluation of their strengths, weaknesses and technical feasibility. Three specific case study applications of on-animal sensors were explored through industry partner interview to evaluate the technical feasibility of the proposed systems delivering on integrity system requirements. In all case studies (FMD detection, PCAS accreditation and transport welfare) the theoretical potential for on-animal sensors was supported.

However, several key issues need to be addressed before a whole-sale (or even partial) transition to an on-animal sensor-based Integrity System should be considered:

1. This technology is only now emerging as a commercially available tool and as such still requires significant technical evaluation and likely refinement.
2. Critical to success is the long-term reliability and retention rates of any on-animal sensor system to be used. This will need to match or exceed the performance of current NLIS ear tags. As at the time of reporting, no long-term tests (>3 months) of any emerging on-animal sensor systems have been reported.
3. There is little base line economic data to enable an estimate of the potential industry level benefits that an on-animal sensor-based Integrity System might bring. There is a key need for research into the likely benefits and costs that these technologies might bring in terms of biosecurity, product integrity and animal welfare claims as opposed to on-farm benefits.
4. Benefits to producers outside the NLIS functionalities could be significant. This is dependent on the complexity of the system implemented and the production system of application. Nevertheless, benefits should be considered as a win-win and leveraged in terms of cost reduction of the NLIS implementation.
5. Producer perceptions of the use of data from advanced sensing systems will be critical with adverse reactions to the concept of "big brother" watching their animals resulting in significant push back. Strategies will need to be considered to overcome this risk.

13.2 Recommendations

1. To inform future investments, an economic analysis of the potential benefits that these systems might bring needs to be undertaken. This economic analysis should focus on the value proposition around specific integrity system functions (both current and future) such as biosecurity, product authenticity and animal welfare claims. This critical information will help both MLA and technology developers prioritise investments.
2. An on-animal sensor, preferably in ear tag form factor, with absolute location (GNSS) and activity sensing (accelerometer or similar) will likely be of significant value for future integrity system functionality and the development of these systems should be pursued by the industry concurrent to the continued use of existing NLIS technologies. In an initial phase, this might best be supported by facilitating small scale case study projects. These projects would be based around a key integrity system function and provide technology developers with the opportunity to have their equipment evaluated in this specific context.
3. One of the key pieces of information currently not available to the industry is the likely retention rates of sensor ear-tags of varying weights and pin configurations. A long term (>3 years) independent study exploring this simple concept could provide valuable insights for technology companies seeking to develop suitable hardware solutions for a future integrity system.
4. While an on-animal sensor appears to be the most viable option other technologies could provide benefits across specific functions of the integrity system. Examples include integrating DNA tracking for post-processing product tracking and satellite based remote sensing of livestock numbers and locations. These could be considered for initial economic evaluation and then where viable considered for case study evaluation.

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15. Appendix A: Details of current commercial platforms applicable to livestock industries

Note this list is not exhaustive. This information has been collated from publicly available information. The details are correct as of the time of publication. However, there are likely to be changes to each as development continues. Acronyms used: ACC: accelerometer; DNP: Detail not provided or disclosed; GNSS: Global Navigation Satellite System; IMU: Inertial monitoring unit; SC: Stationary camera; Temp Sensor: Temperature sensor

Primarily location or attribute tracking	Company/ Device Name	Website	Location	Stated Objectives	Form Factor	Technologies	Data communication	Energy management	Extensive beef	Intensive (dairy or feedlot)	Sheep	Goats	State of development
Location	Agersens	https://www.agersens.com/	Australia	Virtual fencing	Collar	GNSS IMU	LoRa	Solar	Y	Y	N	N	Under development
Attribute only	Allflex	https://www.allflex.global/au/product/sensehub-for-beef/	UK	Reproduction Health Nutrition	Collar Ear Tag	DNP but possibly ACC	ZigBee	DNP	Y	Y	N	N	Available for purchase
Location & attribute	Australia Wool Innovation Smart Tag	https://www.wool.com/on-farm-research-and-development/sheep-health-welfare-and-productivity/smart-tags/	Australia	Movement tracking Social interactions	Ear tag	ACC Proximity sensor	DNP	Solar & battery	N	N	Y	Potentially	Under development
Attribute only	Biondi Engineering SA	https://www.biondiengineering.com/	Switzerland	BCS	SC	3D Imaging	DNP	Cable power	N	Y	N	N	Unclear but presumed under development
Location & attribute	Cattle watch	http://www.cattle-watch.com/	Israel and South Africa	Geofencing Stock theft Disease detection Pregnancy Oestrus detection	Collar	DNP LPWAN for tracking purposes	Mobile network Direct to satellite NB-IoT for gateway relay	DNP	Y	Y	Y	N	Available for purchase
Location & attribute	Ceres Tag	https://www.cerestag.com/	Australia	Location Health Welfare Stock theft	Ear tag	GNSS ACC	Direct to satellite	Solar	Y	Y	N	N	Under development
Attribute only	CSIRO eGrazor	https://www.csiro.au/en/Research/AF/Areas/Livestock/eGrazor-measuring-cattle-pasture-intake	Australia	Feed intake	Collar	GNSS IMU	DNP	Solar	Y	Y	N	N	Under development

Attribute only	DeLaval	https://www.delaval.com/en-au/	Sweden	BCS	SC	3D Imaging	DNP	Cable power	N	Y	N	N	Available for purchase
Attribute only	FeverTags	https://fevertags.com/	USA	Health	Ear tag	Temp sensor	WiFi	DNP	Y	Y	N	N	Available for purchase
Attribute only	HerdDogg	https://www.herddogg.com/	USA	Health	Ear tag	Motion sensor (DNP) Temp sensor	Bluetooth	DNP	Y	Y	Y	Y	Under development
Location & attribute	IDS G Farm	https://ids-gfarm.com/	Australia	Location Health	Ear tag	GNSS RFID Temp sensor	LoRa WiFi Mobile Networks	Solar & battery (approx 5 year lifespan)	Y	Y	Y	Y	Available for trial
Attribute only	Moocall	https://moocall.com/pages/moocall-australia	Ireland	Heat detection Calving detection	Collar (Bull) Ear tag (Heifers)	Proximity sensor Motion sensor (DNP)	Mobile network	Rechargeable battery (approx 30 day per charge)	Y	Y	N	N	Available for purchase with subscription
Location	mOOvement	https://www.moovement.com.au/	Australia	Location	Ear tag	GNSS	LoRa	Solar & battery	Y	Y	N	N	Under development
Attribute only	Nanotron Swarm Bee	https://nanotron.com/EN/pr_livestock_management-php/	Germany	Location Health Oestrus detection	Ear tag	GNSS	UWB	DNP	Y	Y	DNP	DNP	DNP
Location	Nofence	https://www.nofence.no/en/	Norway	Virtual fencing	Collar	GNSS ACC	Bluetooth Mobile network	Solar with integrated battery	Y	Y	Y	Y	Available for purchase
Attribute only	Optiweigh	https://optiweigh.com.au/	Australia	Weight	Weigh scale	Weigh scale RFID reader	DNP, but works without mobile coverage	Solar with integrated battery	Y	Y	N	N	Unclear but presumed available for purchase
Attribute only	Quantified Ag	https://quantifiedag.com/	USA	Health	Ear tag	Motion sensor (DNP) Temp sensor	DNP	Lithium battery	Y	Y	N	N	Unclear but presumed available for purchase
Location & attribute	Smart Paddock	http://smartpaddock.com/	Australia	Location Health	Collar Ear tag	GNSS Motion sensor (DNP) Temp sensor	LoRa Mobile network Bluetooth Satellite	DNP	Y	Y	Y	Y	Available for purchase

Location & attribute	SmartBow	https://www.smartbow.com/	Austria	Location Rumination Oestrus detection	Ear tag	Location sensor (DNP) Motion sensor (DNP) Temp sensor	DNP	Battery (approx 2 year lifespan)	N	Y	N	N	Available for purchase
Location	Sodaq Cattle Tracker	https://sodaq.com/projects/cattle-tracker/	Netherlands	Location	Ear tag	GNSS ACC	LoRa	Solar with integrated lithium polyer battery	Y	Y	N	N	Available for purchase
Attribute only	Taggle	https://taggle.com/	Australia	Calving detection	Intravaginal device	DNP	LPWAN Mobile network Satellite NB-IoT	DNP	Y	Y	N	N	Unclear
Attribute only	TruTest	https://www.livestock.tru-test.com/en-au	New Zealand	Weight	WoW	Weigh scale	Mobile network Satellite	Solar	Y	Y	N	N	Available for purchase
Location	Vence	http://vence.io/	USA	Virtual fencing	Ear tag	Location sensor (DNP)	DNP	DNP	Y	Y	N	N	Available for purchase

16. Appendix B: Details of current commercial platforms applicable to non-livestock industries.

Note this list is not exhaustive but provided by way of example. This information has been collated from publicly available information. The details are correct as of the time of publication. However, there are likely to be changes to each as development continues. Acronyms used: DNP: Detail not provided or disclosed; GNSS: Global Navigation Satellite System; IMU: Inertial monitoring unit; Temp Sensor: Temperature sensor

Company/ Device Name	Website	Location	Brief description	Applications (as per website)	Technology	Data communication	Energy Management	State of development
CSIROs Wireless Ad hoc System for Positioning (WASP)	https://research.csiro.au/wireless/wireless-tracking-wasp/	Australia	WASP uses anchor nodes at known locations throughout the environment which communicate with the tags attached to the object being tracked	Emergency Management - tracking and monitoring fire fighters Mining - tracking assets and staff Sport - tracking elite athletes	Radio-based location system	DNP	Battery (2.5-10h battery life)	Under development
Myriota & Future Fleet collaboration	https://myriota.com/2020/07/28/myriota-partners-with-future-fleet-international-to-create-an-advanced-satellite-iot-connected-asset-tracking-device/	Australia	Satellite asset tracking	Agriculture Mining Logistics Transport	Provides the data communication platform for existing devices	Direct to satellite	DNP	Under development
Mobilaris Onboard & Mobilaris Hybrid Positioning	https://www.mobilaris.se/mining-civil-engineering/mobilaris-onboard/	Sweden	Underground navigation	Mining	DNP	Android compatible software Cellular connectivity possible	Dependent on device battery life	Under development
CSIROs Camazotz	https://research.csiro.au/robotics/camazotz/	Australia	Low power autonomous tracking device containing a GPS module, inertial unit, temperature, pressure, and audio sensors. Camazotz can store the data on board until it establishes contact with a radio base station, after which the data is offloaded using wireless radio.	Wildlife tracking (flying foxes) Public bicycle fleet tracking Parcel tracking Livestock tracking	GNSS IMU Temp sensor Pressure sensor Audio sensor	RF (DNP)	Solar powered	Research use

Defence Advanced Research Projects Agency (DARPA) Adaptable Navigation System	https://www.darpa.mil/program/adaptable-navigation-systems	USA	DARPA is investigating alternate sources to GPS for location tracking, including using "signals of opportunity" such as television, radio, mobile networks and satellites. It is attempting to alleviate issues associated with poor GPS coverage in buildings, thick canopy cover and underwater	Military	DNP	DNP	DNP	Archived
ABBYY	https://www.abbyy.com/sdk-for-ocr-and-data-capture-in-machine-vision/	USA	Utilisation of text recognition, barcode recognition and optical mark recognition through machine vision	Supply chain & logistics	Image-based pattern recognition	DNP	NA	Available for purchase
Nanotron	https://nanotron.com/EN/pr_livestock_management-php/	Germany	In addition to the Swarm BEE for livestock monitoring, Nanotron has other technologies available	Mining Healthcare Manufacturing	UWB	DNP	DNP	Available for purchase
Aexonis	https://aexonis.com/	France	IoT company with history in law enforcement and cyber intelligence. Aexonis' flagship product CEMTORE is an open, virtual management software suite. It can management large device numbers and IoT edge services.	IoT data management Law enforcement Cyber security Livestock tracking (new application)	Provides the data communication platform for existing devices	LoRa Bluetooth WiFi Cellular	DNP	Livestock applications under development
Garmin	https://www.garmin.com/en-AU/	USA	Optical HR monitors use a series of lights that flash against the skin. This illuminates capillaries in the body to detect changes in blood volume.	Fitness tracking	Optical HR monitor	Bluetooth	Battery	Available for purchase

17. Appendix C – Detailed analysis of case studies for the application of the proposed systems

Foot and Mouth Disease (FMD)

- **Introduction**

Foot and Mouth Disease (FMD) is an acute, highly contagious viral disease of domestic and wild ungulates (mammals with hooves such as cattle, pigs and sheep). The disease is caused by a RNA virus in the *Picornaviridae* family. There are seven serotypes, and within each are several strains that differ in their infectivity for various species. FMD affects the terminal layers of the skin and causes the skin to separate. Clinical signs in cattle and pigs are more obvious than sheep. Symptoms range from mild and inapparent to severe and include: dullness, poor appetite, excess salivation, acute lameness, fever, decreased milk yield (in dairy species), and the formation of fluid-filled blisters (vesicles) and erosions in the mouth, nostrils, teats and skin around the hooves.

FMD is highly transmittable. It is through the movement of infected animals, contaminated vehicles, equipment, people and products that the disease spreads through herds, farms and regions (AHA, 2019). The route of infection is most commonly through inhalation of viral particles, or in the case of pigs, ingestion, although infection may also occur through minor abrasions on the feet, mouth, nose and udder. Large quantities of the virus are excreted in expired air, secretions and excretions, and can occur up to 4 days prior to the appearance of clinical signs. The incubation period is generally 14 days, although this is dependent on the viral strain and the route of transmission. Although mortality rates in adult livestock are low, in young animals it can be much higher. In general, cattle and pigs are more severely affected than sheep and goats (AHA, 2019). Case study participants described FMD as a disease which affects the whole herd, causing low rates of mortality but high production losses.

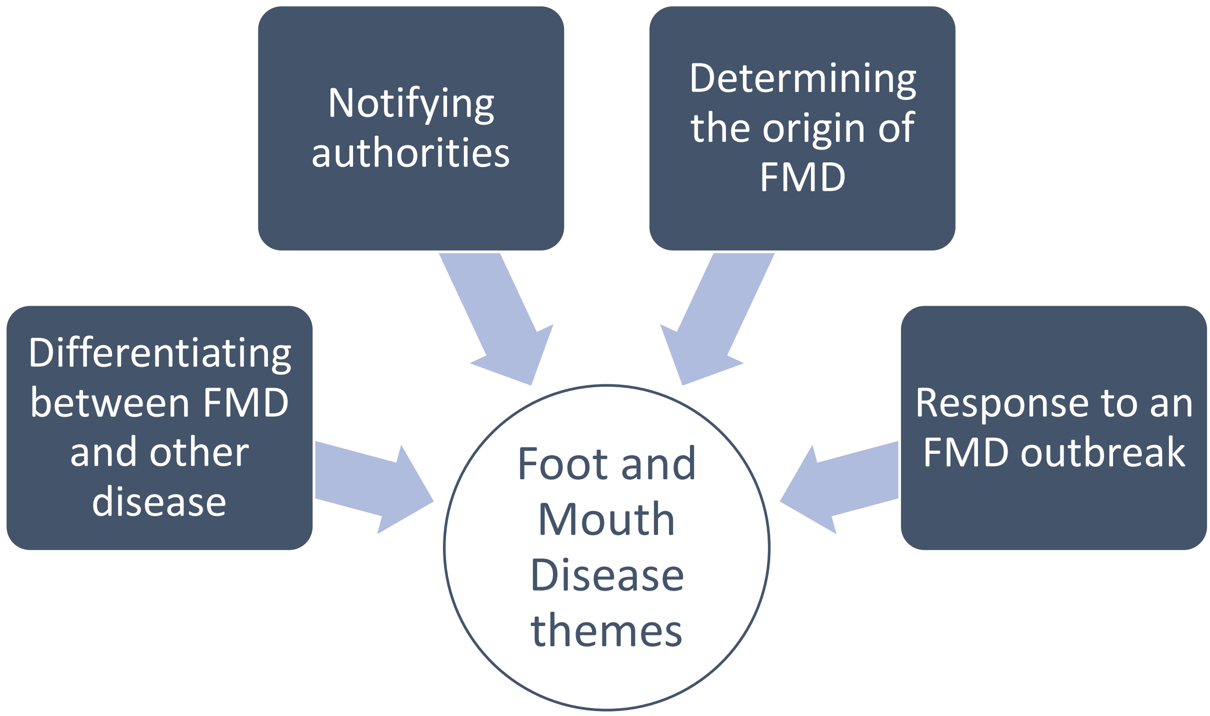
Australia is one of the few countries free from FMD, with the disease endemic in other parts of the world such as Asia and Africa. FMD is considered an emergency disease in Australia due to the serious production, financial and societal impacts an outbreak would have on the livestock industry and supporting sectors. The presence of FMD would be a major constraint to international trade. Australia currently exports around 60% of red meat products to over 100 countries (MLA, 2020), much of which is to FMD-sensitive markets, if an outbreak were to occur it would have a significant impact on the industry. It is likely that FMD-sensitive countries would impose trade bans on Australian products, which would subsequently divert products to the domestic market leading to reduced prices received by producers. In the case of a small outbreak, the estimated cost is approximately $6 billion over 10 years. If the outbreak was larger, this cost is estimated to be $52.5 billion over 10 years, with a loss of export market access costing a further $1 million to the supply chain each day (Xinova,2019). Societal impacts would be at individual, household and community levels and include reduced mental health and welfare, and loss of income and production.

Under the current NLIS system, if a producer suspects that an animal is showing clinical signs of FMD, they must report this to their local veterinarian, state or territory department of primary industries, or call the Emergency Animal Disease Watch Hotline. Once diagnosed, Australia's policy is to contain, control and eradicate FMD as quickly as possible. At the time of diagnosis, movement restrictions will be put in place with a national standstill of all susceptible animals implemented immediately and lasting at least 72 hours. During this time, tracing of animals, people and product movements would occur (AHA, 2019; Buetre et al., 2013).

The National Traceability Performance Standards (AHA, 2015b) were mentioned by participants and described as the benchmark for response times if an FMD outbreak was to occur. Most importantly, once diagnosed, trace back of animal location for the past 14 days is required. Trace-forward is also applied for 14 days from the date of the first report (AHA, 2019). Infected properties and dangerous contact premises (those with a high likelihood to have an infected animal or contaminated animal products) are placed in a restricted area of at least a 3km radius in which there is no movement of people, machinery or animals (people must go through a decontamination process). There is then a control area placed around the restricted area of at least a 10km radius. The size of these restricted areas is dependent on the size of the outbreak, terrain, pattern of livestock movements, weather, feral animals and livestock concentrations (AHA, 2019). The primary and initial control strategy involves 'stamping out' (destruction and disposal of all animals on infected and dangerous contact premises). This could also be supported by extensive or targeted vaccination depending on the scale of the outbreak (Buetre et al., 2013). To assess the socio-economic impacts and determine the most appropriate and cost-effective control strategies, the size of the outbreak must be defined quickly (Buetre et al., 2013). To reduce the impacts of an FMD outbreak, response preparedness is imperative (Buetre et al., 2013) including improving traceability of at-risk livestock.

Key areas where a future integrity system incorporating 'smart tags' could assist with the detection and response to an FMD outbreak were identified by industry participants during consultations are outlined in Figure 5 below.

Figure 5. Key themes identified from FMD consultations related to sensor-based management.



The weakness of the current system is that it requires a producer to identify and report a suspected case of FMD in a timely manner. Additionally, it relies on a producer being able to **differentiate between an animal that has suspected FMD and other diseases** with similar symptoms. Producers must also **report their suspicions to authorities in a timely manner** and due to trust issues and the potential economic and societal impacts, this often does not occur. If a diagnosis of FMD was made, it will still be difficult to **determine the origin of the disease** using the current system. The timeframe for infection of FMD to an **emergency response** could be several weeks as a result of delays in detection and reporting as suggested by one participant. This is supported by previous studies that have modelled the time from incursion to detection and found that the time between these events could be 20-33 days (Martin et al., 2015). Being a highly contagious disease with a short incubation period and the involvement of naive animals, the disease could spread throughout livestock on that property and beyond before the producer has identified a problem. Each of these themes were then discussed considering the relative advantage of future tracking systems and the implications these systems have for producers.

- **Identification of sick animals and differentiating disease**

Current Situation

Several case study participants suggested a major delay in the reporting of FMD is related to producers being more likely to notice and report a disease in their animals when a group of animals begin showing signs such as lameness or death, rather than a single animal showing signs of disease. 'FMD is a whole herd disease' and this time delay will likely be longer in extensive systems where producers do not see their livestock as regularly as compared to those managing more intensive enterprises. '*In fact, what usually happens is that the producer either doesn't see the sick animals, particularly in a more extensive environment. It's different for a dairy of course because he's in all the time. But in an extensive situation, they may not be aware of certainly a few animals dying*.' However, disease spread in extensive systems would likely be slower than in intensive systems.

Further delays in detection and notification can result because FMD can be very difficult to distinguish from other diseases as there are several differential diagnoses including: swine vesicular disease, mucosal disease, laminitis, hoof abscesses, footrot, scabby mouth, photosensitisation and many more. '*So the signs, particularly milder signs of foot and mouth disease, could be misconstrued as something else like three-day sickness…*'. Therefore, FMD should be considered in the differential diagnosis when vesicles are observed, and a provisional diagnosis made when a combination of clinical signs are observed (AHA, 2019). However, vesicles in the mouth or on the feet might be difficult to see without the animal being in a crush, and in some cases, clinical signs might not be apparent at all. Participants said that this is even more difficult on extensive properties when observation of livestock is infrequent. '*And if they don't see the animals from one week to the next, well, then you can't claim that you're really observing them enough to detect anything that's a problem. So, you could say that your sensitivity to detect FMD on a very large cattle property could be quite low*.'

Consideration for Future Systems

The risk of FMD changes depending on location throughout the country. Location will impact on the risk factors for its incursion and spread and susceptible hosts. Risk decreases with remoteness because the risk of occurrence is related to population size. One case study participant suggested that resources should be invested in intensive and high-risk production areas, (such as dairy farms or feedlots) where FMD is more likely to occur and spread rapidly. Another participant suggested that remote areas require a future Level 4 system more because they are less likely to physically identify FMD.

Participants believed that it would be important to consider whether a 'smart tag' would detect FMD better than visual inspection of animals. They questioned whether the information obtained from the 'smart tag' on every animal would be better than the sensitivity of a number of visual inspections throughout the day. One participant thought the technology might be better in this instance because it can monitor animals constantly and algorithms could be written to detect certain diseases. Another participant also agreed this would be the case, particularly when livestock are checked infrequently. Participants suggested that the 'smart tag' would be better at identifying differences in gait due to the large amounts of data collected, compared to a producer who can only observe their livestock when they are in close proximity to them or differentiating between healthy animals and sick animals But, health issues are common in livestock and it is not possible to respond to every case that be suspected FMD as noted by one participant, '*First of all, there's a lot of animals get sick throughout Australia. And if you responded-- you could not possibly respond to all of them…. And so you're going to have an issue about how you're going to sift through your data to find out what's actually useful*.' Therefore, in order to use a 'smart tag' for the detection of FMD, it will need to be able to differentiate from animals that are sick or injured.

- **Notifying authorities**

Current situation

Another issue presented by participants was the delay in producers reporting disease to officials, subsequently prolonging the time between identification of FMD and an emergency response. '*The nub of the whole surveillance conundrum, really, is to get those people that are on the farm, who are the eyes and ears, to act as you want them to act*.' Some producers may not report disease to an official immediately and instead, might discuss the situation with someone they trust, such as a neighbour or family member. However, as the index of suspicion increases, they might be more inclined to talk to a private or government veterinarian who will move forward with the process of taking samples and placing restrictions on that property.

As put by one participant, the likelihood of a producer reporting a disease will be based on their '*willingness to be a part of the industry and be part of the solution and not [be] part of the problem'*. One participant mentioned that many outbreaks have occurred where producers have not reported the suspicion of disease in their livestock. In remote areas, it could also take quite a long time between a producer identifying clinical signs and contacting an official who can attend the property and obtain a result. Some case study participants suggested that producers in more intensive systems might be more likely to have a better relationship with their vet as they see them more regularly, which could reduce the time between detection and response. The relationship between government and producers has also changed from providing support for productivity and profitability within their enterprise, to acting as a more regulatory body in the notifiable disease space. This raises concerns with some producers who are wary involving the government and alerting people that they have a problem on their property.

Several case study participants highlighted that it is important to understand the consequences to a producer if they raise a concern and it ends up being a false alarm. Some producers may be hesitant to report a notifiable disease if they are not confident in their ability to detect issues in their livestock. Other producers might be more confident in making their own assessment due to a long history in the industry or veterinary support, and they might feel they can make the decision rather than going to the effort of contacting an official. 'Some people are not very keen on involving-- first of all, letting anyone know they got a problem, and secondly, not keen on involving government.' This was supported by another participant who pointed out the conundrum that no producer wants to be the one that missed reporting the disease, but they also don't want to be the one who instigates a response which results in a false alarm.

Considerations for Future Systems

Additionally, several participants were concerned that industry stakeholders would not appreciate the government showing up at their property when the technology identifies a few suspect FMD cases. They emphasised that identifying a threshold of affected animals (for example three-quarters of the animals on a farm) or a percentage of the herd showing clinical signs and a certain severity of symptoms would be critical. They acknowledged that this would be difficult and needs to be based on individual circumstances. To try and identify a small number of infected animals would risk false alarms, but some participants highlighted that if only one animal is showing clinical signs, the animal is unlikely to have FMD due to the disease being highly contagious. Alternatively, if the 'smart tag' had algorithms that could detect disease and alert producers, rather than the government, producers might have greater confidence in reporting it and not being the centre of a false alarm.

Participants thought that ideally, the 'smart tag' would identify a problem that needs to be investigated and the location of the animal. This would also allow officials to quickly look at neighbouring properties and determine whether there are any early clinical signs of FMD in livestock on those farms. Participants broached concerns about the difficulty for sensor technology to gather enough information for early warning signs. As summarised by one participant, '*in some situations we're going to be able to say, "Hey, it's that disease, for sure." But in many situations, we're just going to be able to say, "Hey, there's something wrong. We don't know what it is, but there's something wrong*".' Finally, participants highlighted how a 'smart tag' could be used when trying to trace the outbreak because it could show progression of the disease and an emergency response could be implemented as quickly as possible.

- **Origin of FMD**

Current Situation

Participants expressed concern that it would be difficult to determine where FMD originated, noting that it would likely be detected at either end of the supply chain (producer or processor). One participant mentioned that suspected cases have been identified at slaughter and have been traced back from there. Other suspected cases have been identified by private veterinarians on-farm. When there is suspicion of FMD, the vet will take samples which will be sent for testing as quickly as possible, but there are issues that might slow the response process from onset of disease to an emergency response.

Considerations for Future Systems

Participants identified a number of gaps within the current NLIS that sensor technology could address. At the moment, if an outbreak were to occur, gathering data on livestock movements between properties of the same PIC would be based on relationships and trust, so 'being able to verify it with data like this [from a 'smart tag'] would be better'. Participants agreed that a 'smart tag', and in particular GPS, would help fill the gaps in the current system and benefit traceability and non-compliance in the event of a disease outbreak. '*I would have thought that [a 'smart tag'] would be extremely valuable because it gives you one more method of verifying where the animals have exposed themselves to others*,' one participant discussed.

- **Response to an FMD outbreak – Traceability and Compliance**

Current situation

The weakness with the current system is that it relies on producers to fully comply with all aspects of the NLIS. Additionally, as it is only compulsory for cattle (and sheep in Victoria) to have NLIS tags, it will be difficult to trace all animal during an FMD outbreak.

Case study participants believed that the NLIS had improved and sped up tracing capabilities from having to physically look at each animal, but there are still important gaps that need to be addressed. For example, movements of animals are sometimes not lodged immediately (or at all) when sold or for temporary change of locations, such as a bull being sent around to multiple properties to serve cows. This can result in an animal being registered for the wrong property and subsequently the incorrect location could be quarantined in the event of an FMD outbreak. Additionally, multiple land parcels being registered under one PIC can affect how livestock movements are recorded between producers' own properties. In the event of an FMD outbreak, land parcels that are a long way apart, but under the same PIC, will have an impact on the restricted zone boundary imposed.

Participants agreed that traceability of cattle is better than sheep and goats due to compulsory NLIS tags in Australia. In order to advance disease response, NLIS tags on individual sheep, goats and other livestock species is required. Currently, it is only Victoria where sheep must have NLIS tags (in all other States it is voluntary). There are also other inconsistencies between states such as the distance allowed between properties to be registered under the same PIC. Another inconsistency with the NLIS is, in some jurisdictions, animals only need to be tagged before they leave the property of origin. Therefore, on some properties, livestock cannot be accounted for in the event of an FMD outbreak because they might never have been registered under the NLIS if they have never left the property of origin. One participant explained that some producers do not see the value in purchasing tags that some animals will lose before they have even left the property of origin and would rather just tag and register animals immediately prior to moving them. These gaps in the NLIS lead to longer delays because officials have to talk to producers, obtain their paperwork and spend time filling in the data gaps to full trace an animal.

Consideration for Future Systems

Participants stressed that traceability during an outbreak is vital, and it is important to establish how fast the disease is progressing so that restriction zones can be put in place around infected animals. It is important that the emergency response can get ahead of the disease because all infected animals and their contacts will be stamped out, and reducing the number of affected properties is of primary importance. Participants perceived sensor technology to be extremely valuable because it will provide information on the animals' life history and provide additional methods for verifying where animals have been exposed, allowing the response team to identify location, movement and contacts quickly. Participants agreed that improving the current system and saving even just 24 hours would make a difference to an emergency animal disease response.

Pasture-fed Cattle Assurance System (PCAS)

- **Introduction**

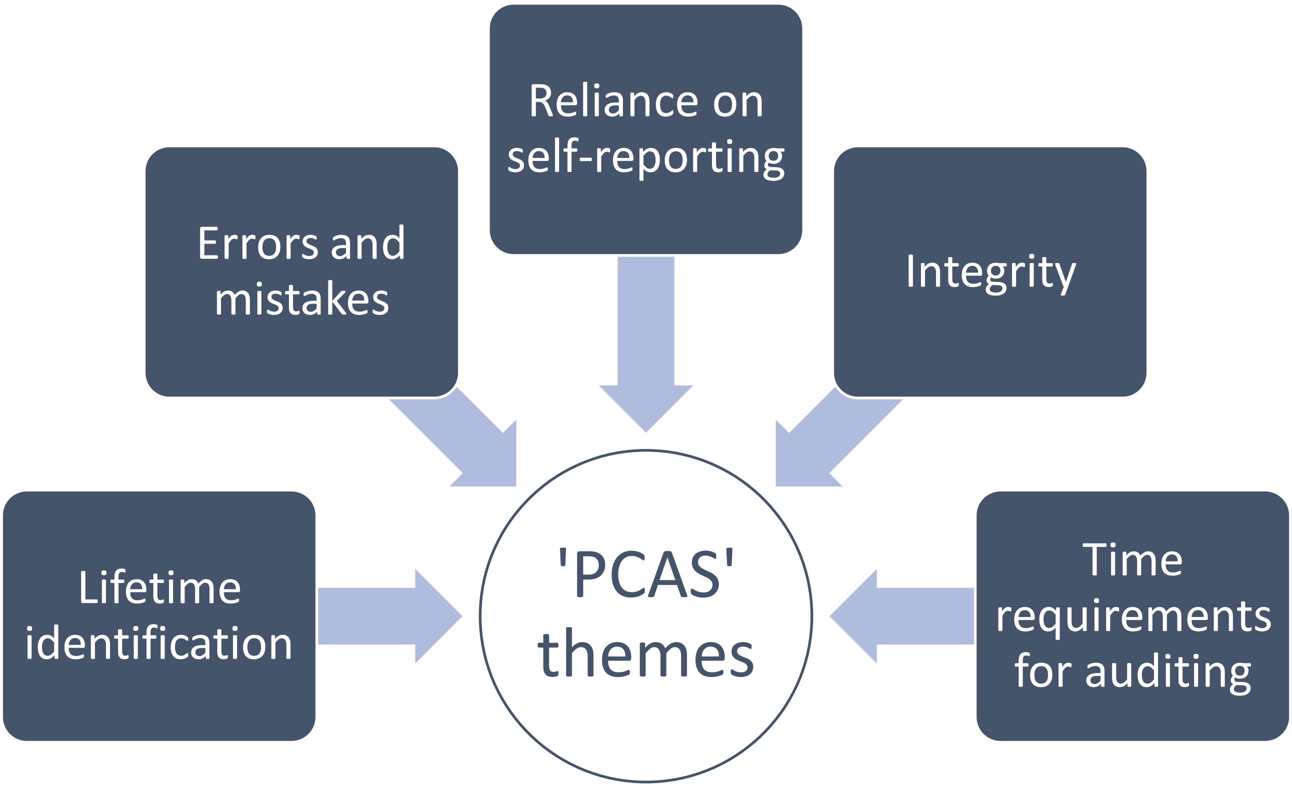
Certification schemes have been in use for approximately 30 years and play an important role in maintaining integrity across the red meat supply chain (Vogt, 2019). They often reflect industry best practice on many aspects of livestock production such as animal welfare, eating quality and environmental sustainability. Most schemes are typically regulated on a voluntary, rather than a legislative basis and are often managed by individual processors (e.g. Teys), supermarkets (e.g. Coles) or industry organisations (e.g. Cattle Council of Australia). The organisation who manages the scheme will set the criteria and audit requirements that need to be satisfied. Certification schemes vary from providing assurance on minimum levels of welfare, to being outcome-based, to a continuous improvement approach whereby regular monitoring of pre-defined criteria occurs (Main et al., 2014). Research has shown that consumers are more inclined to demand and pay a premium for certified products when they believe the approach used by the scheme is sustainable (Singh & Pandley, 2012). There are a variety of certification schemes available to producers and processors that will attract a higher premium for their product. These include the Pasture-fed Cattle Assurance System (PCAS), Australian Livestock Processing Industry Animal Welfare Certification System (AAWCS), JBS Farms Assurance, European Union Cattle Accreditation Scheme (EUCAS) and Meat Standards Australia.

PCAS is a voluntary assurance scheme run by the Cattle Council of Australia. The scheme enables producers to substantiate claims relating to pasture or grass-fed cattle, pre-slaughter methods, time of confinement and individual animal lifetime traceability. To gain certification, producers are required to prove that they operate a grass-fed production system, comply with the PCAS requirements and maintain accurate records. Producers can determine whether their production system complies by conducting an online self-audit. The self-audit requires the producer to answer questions relating to their production system and provides an indication of whether the enterprise conforms to the PCAS standards. To register, producers provide their PIC, pay an annual administration fee ($200) and arrange for an on-site audit with an approved PCAS certification body. The producer must cover the costs associated with the on-farm audit (on average $850, but will vary between certification bodies and the complexity of the audit) and any associated travel costs (Pasturefed Cattle Assurance System 2016).

Consumers both domestically and around the world expect that the Australian red meat industry utilises best practice when producing livestock for consumption. Certification schemes secure the reputation of Australian farms, allow access to new markets and add price premiums to livestock products. To maintain Australia's reputation and integrity, it is imperative that information provided through certification schemes is valid.

Key areas where a future integrity system incorporating on-animal sensor technology could assist with product authenticity claims were identified by industry participants during consultations are outlined in Figure 6 below.

Figure 6. Key themes identified from PCAS consultations related to sensor-based management.



- **Lifetime identification, location and time in confinement of individual animals**

The weakness of the current system is that lifetime individual identification of livestock occurs using NLIS and/or visual tags to enable eligible and ineligible animals for certification schemes to be recognised. The current system was described participants as a 'paper trail' that is 'only as good as the person that's writing on the piece of paper'. It relies on self-audits and trust that producers are adhering to the standards and have accurate and up to date records.

The key aspect of any livestock certification scheme is being able to accurately identify individual animals which comply with program requirements and trusting that records for a range of aspects (nutrition, management practices and health treatments) are correct. Across the supply chain, there are also benefits of knowing when and where animals are located including reducing the number of mistakes entered into the current NLIS database and on-farm records. Technology removes the responsibility of the producer needing to read tags, rely on on-farm records and upload data because the system would be automated. As explained by one participant '*it's taking that responsibility of having to go home, remember to upload that data when you're stuffed at the end of the day, and the computer's … connection's no good*.' The automation of data collection would also save producers time, energy and result in 'less mistakes'.

Under the current system, producers self-report during an audit the duration livestock have been confined in yards for eligible animals. Participants acknowledged that there is the impetus to lie during an audit, particularly if it would result in animals being excluded from the PCAS system. Benefits in having access to information from a 'smart tag' include in a '*PCAS policing type of situation if you could go through and easily track an animal's lifetime movements*' to quantify the length of time spent confined. But benefits stated varied greatly between participants, including one person noting there would be '…*really good on-farm benefits, but I don't necessarily see that there's industry benefit.'* Conversely, another participant reporting *'from a farmer perspective… probably not, because you know what you're doing. But from an industry perspective, it's certainly something that would be able to fight your current affair type stories in terms of policing it [certification schemes*].' Another participant felt that '*the value … gets absorbed at the processing [stage] and that's the big trouble with lifetime traceability because they [the processor] never want[s] to unleash the value back to the producer'*.

Could a Level 1 System help and how?

A Level 1 System could provide individual identification of animals as they depart from the farm and arrive at another destination, including the time they were in transit and any spelling periods. This would assist with accurate and up to date record keeping and livestock transfers. However, a Level 1 System provides no quantification of livestock movements or time spent confined for compliance of the PCAS. It also does not assist with lifetime identification of animals.

Could a Level 4 System help and how?

GPS technology in a 'smart tag' of a Level 4 system would provide continuous location information of individual animals. This data could identify and consequently exclude animals that do not meet standards such as exceeding the time allowed in confinement. Furthermore, under the PCAS, cattle need to be managed as a single mob for a minimum of 14 days prior to dispatch for slaughter. A Level 4 system would allow the identification of animals that do not meet this requirement. 'Smart tag' will be able to provide real-time information about the behaviour, location and state of an animal to ensure they meet certification requirements. However, a 'smart tag' may also have similar retention issues to current NLIS or visual tags therefore lifetime traceability may be compromised. Rumen boluses for identification purposes only could be considered.

- **Specific comments from participants about future systems**

Whilst most participants could see the value in a future system, the benefits were perceived to vary across the supply chain. There are '*two sides in this industry and sometimes we're at war with each other - if the processor is getting the benefit of the premiums from a grass-fed product, but we're not*', then it was unclear of the return and need of a future system for producers. Location information from GPS technology in the 'smart tag' could identify animals that do not meet standards. However, prior to excluding animals from the scheme, producers would need to be given the opportunity to verify claims that animals do not meet the PCAS requirements. This could include to support animal welfare and production outcomes such as '*you're actually doing it for an animal welfare production outcome. You're not confining those animals to try and get around the system or anything*.' Most importantly, a future system with 'smart tag' technology 'adds integrity', improving the perception of industry and accountability of all in certification schemes.

One participant did not see the advantage of lifetime identification and traceability using 'smart tags' because many options including NLIS tags, visual tags and brands already exist. A known limitation of the current system was tag retention negating the ability to confidently identify eligible and ineligible animals, and it was difficult to see how a 'smart tag' would alleviate this issue. To provide producers with confidence that a future system will be better than what is currently available, high levels of retention of a 'smart tag' under commercial conditions must be verified. One participant noted that they believed a 'smart tag' would not replace branding as '*there's too much tradition'* with brands and noted that a future traceability system needs to consider the incorporation of this form of identification.

- **Reliance on self-reporting for audit purposes**

The weakness of the current system is its reliance on producer self-reporting at audit. There are set requirements in terms of animal nutrition, health and welfare in order to comply with the PCAS, but there are limited methods to verify producer claims and acknowledge loopholes in the current system.

- **Livestock nutrition**

Under the PCAS, livestock must have access to graze open pasture, be supplemented with only approved feeds, be provided with a rising plane of nutrition prior to slaughter and restrictions are imposed around grazing of cereal grain crops. Under the current system, it is difficult to verify whether an animal has met all of these conditions, as all information is recorded by a producer and self-reported at an audit. Data from a 'smart tag' would allow producers to 'substantiate their claims', and also provide access to historical information when purchasing animals to guarantee they are suitable for the PCAS, '*because sometimes [I've] bought cattle, and they're just not quite what they described*.'.

- **Animal health and welfare**

  - **HGPs**

A requirement of the PCAS is that no HGPs (Hormonal Growth Promotants) have been used. Other certification schemes also require animals have not been given antibiotics. Whilst the presence of a triangular notch in the right ear of an animal, or the presence of an implant or steel bead might be present, the main way to verify if an animal has been given an HGP is through a National Vendor's Declaration (NVD) (Integrity Systems, n.d.) and self-reporting by producers. There are acknowledged loopholes in the current system as it relies on the honesty of the producer. The risk of failing to properly declare the use of HGP puts in jeopardy the integrity of Australia's traceability system and market access. Although there are penalties for providing incorrect information on an NVD, it is difficult to verify these claims.

  - **Sick, injured or poor temperament animals**

Animals which are, or have been sick or injured or have a poor temperament should not be consigned under the PCAS. Training of staff to recognise these issues was evident by participants, but despite this, not all sick or injured stock will be identified, especially in extensive systems when animals are observed infrequently. It is often difficult and not practical to identify animals of poor temperament and separate these from a mob. Additionally, the determination that an animal is of poor temperament, as opposed to stressed at a certain point of time is highly subjective and judgments will differ between producers.

Could a Level 1 System help and how?

There is no benefit of a Level 1 System to improve self-reporting at audits to verify animal nutrition, health and welfare claims in order to comply to the PCAS.

Could a Level 4 System help and how?

A major benefit of a Level 4 System is being able to verify animal nutrition, health and welfare requirements for the PCAS. There would be an increase in the level of monitoring of animals in extensive areas of Australia through GPS information from a 'smart tag'. Additionally, algorithms using accelerometer data could identify sick or injured animals that would otherwise likely go without intervention. The combination of GPS and accelerometer information would increase the timely identification and treatment of animals providing producers with a benefit outside certification requirements.

Accelerometer data from a 'smart tag' allows animal behaviour to be monitored, and importantly used to indicate behaviour differences when an animal is consuming pasture compared to supplementary feed. Coupled with the location and movement data from the GPS, a 'smart tag' could verify that animals have had access to pasture on a rising plane of nutrition, highlighting animal needs have been met at least for 30 days prior to slaughter.

An additional benefit that can be derived from a Level 4 system that utilises GPS technology is the incorporation of other data streams such as satellite imagery could be incorporated to verify claims related to access to and quality of pasture (Edirisinghe et al., 2011). Knowing the location of animals, overlaid onto a satellite image could confirm compliance in respect to nutrition and feed requirements including access to open pasture and a rising plane of nutrition prior to slaughter.

One option that would need to be explored further is to link the PIC supplied when purchasing HGP to an integrity system adding an extra level of verification when producers consign animals. Additional technology would be required, (potentially on the HGPs themselves or algorithms developed to detect implantation) in order to link the use of HGPs in animals to a producer, but if this was possible it would have the potential to provide objective information to verify compliance.

- **Specific comments from participants about future systems**

A key benefit highlighted by participants was that a future system would help improve the perception of the livestock industry due to improved integrity and accuracy in the information provided to consumers. The information would also allow the industry to be proactive in many aspects of their business including the timely treatment of sick animals and ensuring access to enough pasture to satisfy nutritional requirements.

Participants saw a clear benefit from a 'smart tag', that could individually identify sick or injured animals using an accelerometer and algorithm and located using GPS technology. They felt that this would allow an animal to be treated '*in a timely manner. In these extensive areas, a lot of times you don't find animals until it's too late, whether it's calving or three-day sickness or a heap of other things at times.*' Furthermore, as highlighted by another participant, being able '*to euthanise an animal in a timely manner is a good outcome as far as welfare. So yeah, I see huge benefits'.* With regards to the proposed system to detect the use of HGPs, as highlighted by one participant *'if you've got more than one PIC, you could easily buy HGPs on one PIC and use them on the other one*.' An additional benefit which would assist in developing the value proposition for producers is that autonomous monitoring of animals with 'smart tag' technology would save time and producers and staff would have time to complete other tasks or be away from the property and know what is going on.

One participant stated, '*it's the integrity of the system that makes it robust'* and explained that when consumers pay a premium for a product, they expect a guarantee that the claims made are correct. Another participant expressed concern that public scrutiny of a system that is vulnerable to fraud due to a reliance on self-reporting without any objective data could leave the vast majority of producers doing the right thing struggling to maintain consumer trust. Without a way to use objective evidence to defend the industry, the risk associated with the current system was that it could "*blow the premium markets and the grassfed markets out of the water pretty quickly*". Generally, participants thought that consumers would be happier to purchase products from animals fitted with 'smart tag' technology systems because it reduces the ability for the producer to be non-compliant. But consumers would also need to be thoroughly educated on how the 'smart tag' technology works and how it could verify product authenticity.

- **Physical on-farm audits**

Physical on-farm audits form one component of obtaining certification and ensuring compliance, but are time consuming and costly, taking auditors '*about two hours and twenty minutes. But then you've got travel*.' A major cost is travelling to the property, particularly in Queensland or the Northern Territory. As reported by one participant, *when the auditor comes on-farm that they will check vendor declarations and corresponding numbers but the audit system predominantly relies on the honesty of the producer*. One participant reported clients that they '*know clients that absolutely freak out about it. And they spend weeks, weeks. And they stress, and they lose sleep and the whole thing*,' whilst others are not concerned at all.


Could a Level 1 System help and how?

There is no benefit of a Level 1 System to improve and address auditing concerns for Pasture-fed Cattle Assurance Systems.


Could a Level 4 System help and how?

GPS technology in a Level 4 System would be able to locate livestock, compile reports and increase the efficiency of audit preparation. Aspects of certification that cannot currently be easily verified could use both Level 4 System location information from GPS technology and animal behaviour data generated from accelerometers to identify eligible and ineligible animals. Furthermore, audits may not need to be conducted on-farm and instead could conducted autonomously.

- **Specific comments from participants about future systems**

A 'smart tag' capable of recording and compiling information would greatly increase the efficiency of preparing for an audit. All participants agreed that the technology would be beneficial for reducing the time and costs associated with physical audits for certification schemes. But there are also positive mental health benefits if the system can reduce the stress of audit preparation, as indicated by one participant, '*I hate audits. I hate doing it myself*'. A positive of the current system, is that the producer can sit down and discuss the reasons for non-compliance with the auditor and this is an important consideration for future systems. It was also acknowledged that a Level 4 system could save producers money, in terms of labour savings as some elements of the audit could be ground truthed by technology.it is '*really hard to guess but there'd be many thousands of dollars worth of labour savings. I was going to say you'd probably save a good solid week in 12 months out of compliance as a minimum. I don't even want to overstate it...*' Furthermore, one of the biggest benefits is the ability to reduce '*get down to nearly a desktop-type audit with some of this because you could ground truth it with this technology*.'

Participants saw the benefits of a Level 4 system to objectively verify and ensure consumer confidence in certification schemes. One participant stated there would be no issue with data from a future system being provided directly for compliance and auditing purposes, stating, '*If you're doing everything honestly, it would be good*.' They saw an additional benefit of producers either *'going to then leave the system because they're not keeping accurate records, or they're going to want to improve their own system because they want to keep that framework. And there's no one to argue with it. You're arguing with a system that's just recording*.'

Fit to load

- **Introduction**

The Australian Animal Welfare Standards and Guidelines - Land Transport of Livestock (the 'Welfare Standards') provide the standards and guidelines for all people involved in livestock transport and form the basis for consistent legislation throughout Australia (AHA, 2012). The standards apply to all major Australian livestock industries such as sheep, poultry, pigs and cattle. From these standards, the 'fit to load' guide (MLA, 2019) and the Livestock Transport Guide (Australian Livestock Rural Transporters Association, 2020) have been developed to assist users across the supply chain who transport livestock. The 'fit to load' guide (MLA, 2019) ensures best practice of animal welfare by providing guidance to livestock operators (consignor, transporter or receiver of livestock) to assist them in deciding whether animals are in good health and condition to be transported by rail or road. The guide encompasses all aspects of transport from preparing animals to be loaded, deciding on loading densities, managing effluent, to the roles and responsibilities of all participants. The 'fit to load' and Livestock Transport guides include a checklist for consignors to complete before livestock are loaded to ensure clear expectations for all across the supply chain. Best practice for preparing animals for transport include resting recently mustered livestock prior to loading for set periods of time, co-mingling mobs of livestock well before the journey and recording and communicating the date and time livestock last had access to water and feed before been loaded.

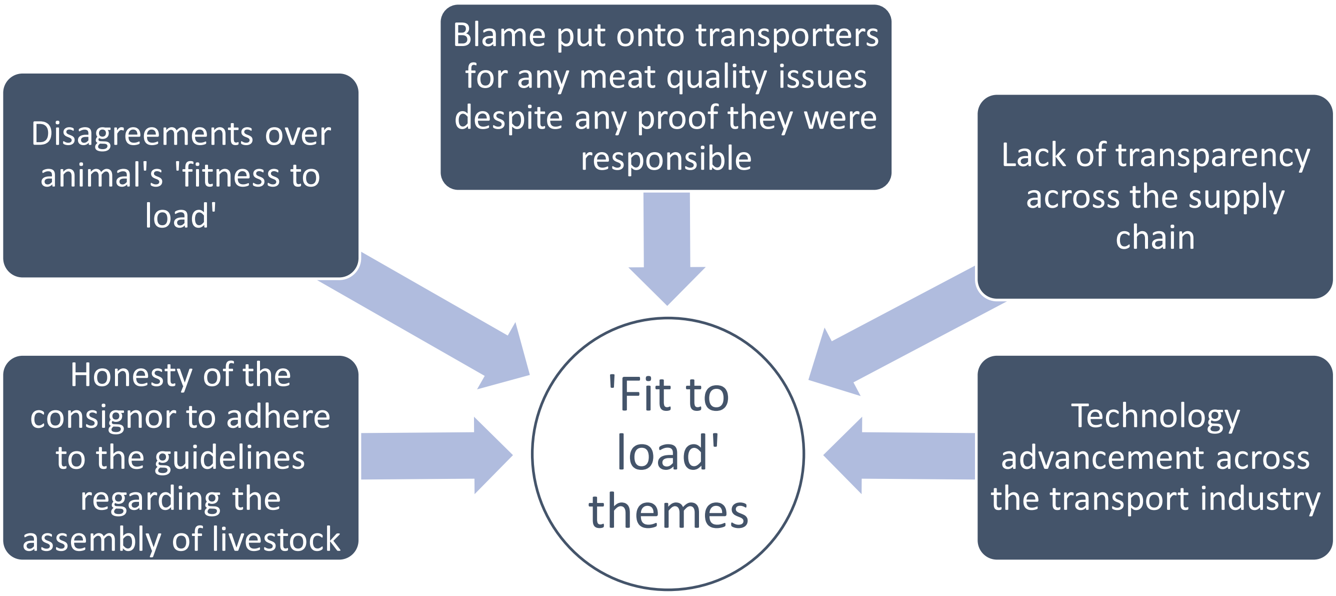
One of the most important aspects of 'fit to load' is that the 'person in charge', that is the person responsible for the welfare of all livestock under their control changes at different points throughout the journey. The consignor is responsible for preparing livestock prior to loading and ensuring holding and spelling periods are met (AHA, 2021; MLA, 2019). From the final inspection immediately prior to loading and throughout the journey, including driving in a manner which minimises negative welfare impacts and unloading at the destination, the transporter is responsible. Finally, the receiver is accountable after livestock have been unloaded. If an animal is loaded and transported, despite being unfit to do so, the person in charge of the livestock at the time may be determined to have committed an act of animal cruelty and be liable for prosecution. Most commonly, it is the transporter who is in charge of making the final determination of whether an animal is fit to load and who is at risk of contravening the guidelines.

An important aspect of transporting livestock is understanding animal behaviour and performing low stress handling techniques. A new animal welfare workshop was piloted in 2020 for livestock transport workers to learn about cattle behaviour and handling techniques in order to promote safer work practices and improve animal welfare outcomes (Condon, 2020). Previous workshops have not targeted the transport industry, which is an extremely important part of the supply chain to ensure high animal welfare outcomes are met. Participants in the current research recognised the high-profile nature of the transport industry to consumers - '*the road transport industry, we are the most visible link in the supply chain*.' There was a perceived lack of understanding from the urban community of the red meat sector.' There was a genuine willingness amongst participants to adopt new practices and technologies that can assist with preventing and addressing animal welfare issues. Additionally, the importance of embracing new practices in order for the sector to retain its social licence, *'...very rarely will they [the consumers] get to go to a processing facility or to a farm but the trucks driving on the highways in Australia is what they see, so obviously, animal welfare needs to be front of mind all day every day*.' It was recognised that things will go wrong, as the industry and processes are not perfect, however, everyone across the supply chain has an important role to play in addressing issues that arise.

A lack of transparency across the supply was highlighted by participants. With pressure growing about the welfare of livestock at a transporter and producer level, there is little discussion about the role at the processor level. Participants highlighted a lack of trust/transparency across the supply chain as an ongoing issue *'[w]e can't go in[to] the meat works and see what they're doing*.' Another participant reiterated this sentiment stating *'... we deliver the animals the best we can, but from there to slaughter, and then even after slaughter, how that product is managed can be a huge detriment to the producer and how they get paid. So, if the animals are treated poorly or have a long curfew or whatever. And then, even when they're then processed...anything to try and make the whole supply chain transparent is a good thing*.' One participant expressed frustration at not knowing at times why animals had graded poorly. There are a number of issues associated with transporting livestock that may lead to breaches in compliance or disagreements between stakeholders arising. These can include losses in opportunity to sell an animal, disagreements due to differences in weights between time of sale and unloading, and failures to lodge livestock movements. The value proposition and potential lost opportunity of an animal not fit to load posed deliberations from participants. An example provided was '*I've got a potential earning of lower-hanging fruit of $1,200 at the moment for a saleable animal….Or if I don't put her on the truck, I've got no return. I've got to biosecurity risk, at best*.' Furthermore, whilst producers were not always looking at placing blame when animals did not grade as expected, they did want to understand the conditions during the journey or at the processor that may have contributed to poor performance. Whilst all parts of the supply chain play an integral role, currently there is little transparency or trust between them.

Key areas where a future integrity system incorporating on-animal sensor technology could assist with animal welfare issues related to 'fit to load' were identified by industry participants during consultations are outlined in Figure 7 below.

Figure 7. Key themes from 'fit to load' consultations related to sensor-based management.



- **Assembly of livestock**

The weakness of the current system is that it relies on the honesty of the consignor to adhere to the guidelines regarding the assembly of livestock. Even if transporters believe animals have not being properly prepared, the absence of an objective measure does not allow them to confidently communicate this to the consignor. Furthermore, failure by consignors to have livestock ready for transportation is a huge driver welfare and fatigue issue.

Transporters reported that one of the biggest challenges in the sector was animals not being prepared properly for transport. Depending on the age and species of the animal, spelling times required vary from 12 to 36 hours (MLA, 2019). Truck drivers recognise that loading animals which have not been appropriately spelled this can lead to significant problems and affects the amount of effluent landing on roads, '*nine times out of ten, the transporter will not have a good day*.' It was acknowledged by one participant that there are differing opinions on how long animals should be curfewed for before they are loaded and the belief that by shortening this period, animals will not lose as much weight throughout the journey. However, transporters stated that if animals are loaded too soon after they have been brought into the yards they must change the way they load and give the animals more room, *'it's not that you're going to not load, you just have to change the way you load. So they're less likely to be laying down in their own faeces and… just give them more room so they've got room to move around*.' This can have an impact of animal effluent landing on roads. Several participants hypothesised that animals which have not been spelled for an adequate amount of time, or are stressed through a journey, produce more effluent. Most importantly, participants noted that it is difficult to dispute the consignor's account of events as '*the problem is if you rattle the feathers too much, there's always someone else there that will do the job*.'

Another ramification of consignors failing to have livestock ready for transportation can lead to driver fatigue. There are implications for driver safety, not just animal welfare, when livestock are not ready for loading, with one participant highlighting '*if we arrive at a property, and the cattle aren't ready or* *they've got delayed, that causes a problem with our fatigue of our drivers. To balance the fatigue and animal welfare is virtually impossible. It is very hard for us*.'


Could a Level 1 System help and how?

There is no benefit of a Level 1 system to confirm that animals have been mustered into the yards and assembled ready for transport according to guidelines. Additionally, nor will the proposed system assist with fatigue related issues with drivers. The majority of large transport companies already deploying a suite of technologies to monitor driver location, duration, breaks and fatigue. This suite of technologies embraced by the transport industry equates to a Level 1 system in terms of providing precise truck location and time information. A similar arrangement to the proposed Level 1 system has previously been explored as told by one participant. However, there was little appetite from the smaller companies and owner-operators within the transport sector to incorporate, as '*the hardest thing is you are putting a responsibility on a driver to do it'*. Additionally, it was recognised that many producers transport their own livestock and it would be difficult to identify all trucks and trailers involved to affix readers, or convince owners to install the technology.


Could a Level 4 System help and how?

The use of the GPS in the 'smart tag' to corroborate the consignor's story and confirm the length of time animals have been in yards prior to loading would be beneficial to back up these anecdotal reports of producers not complying with the guidelines. Tracking the livestock's behaviour using an accelerometer would also provide information to the consignor and transporter about animal activity, which could be used to determine if they are 'settled' and ready to load.

- **Specific comments from participants about future systems**

Trucking company participants saw the benefit of a Level 4 system with the ability to determine the true story, especially with regards to the assembly of livestock in preparation for transport, '*we probably get told a fair few lies at times, like, saying stock [have] been locked up for say 24 hours or whatever, and then they've only been here 10 minutes.*' Participants acknowledged the usefulness of an alert from the 'smart tag' when animals have only just been yarded and therefore potentially need a longer spell before loading. Livestock that have been hurriedly mustered into the yard or have only just arrived may be panting and sweaty, especially if it is a hot day, could be identified. If animals are loaded in this condition, it often leads to effluent tanks on the truck overflowing quickly and livestock not travelling well as they are forced to stand in their own faeces. The benefit of the Level 4 system as perceived by participants would be if the animals are loaded, despite the transporters protests, and if something does go wrong, the information would be available to pinpoint what happened and who was responsible. Information from the 'smart tag' prior to arriving at a property could assist them in organising their loads, '...*if you knew what was going on a little bit, you'd probably push people back and do another job that was more organised than leave up one a bit later in the day or something.. because that's our hardest thing. We don't know exactly what's going on until you actually drive in*.' All transport companies reiterated the difficulty in balancing animal welfare, driver fatigue and the relevant laws and therefore future systems that could help support this weakness in the current system would be of value.

- **Fit to load**

The weakness of the current system is that is relies on the subjective visual assessment by an individual, and for the consignor and transporter to both agree, to determine whether animals are fit to load. Disagreements over whether animals are fit to load, whilst not common are of a huge concern because of the legal implications for the transporter.

All participants in the transport industry recognised the difficulties in balancing business relationships with the fit to load guidelines. Currently, they found it tricky to not load animals when consignors argue they are suitable for transport. Additionally, it was hard to spot some illnesses or injuries which deem animals not fit to load e.g. eye cancer depending on the position of the transporter as the livestock move onto the truck. Participants acknowledged that it is unacceptable to consign sick or injured animals to the abattoir, but with current livestock prices so high, producers are pushing the boundaries and seeking to load as many animals as possible, albeit some that are perhaps not 'fit to load' according to the guidelines, '*but if this system takes out the argument, and there's this standard'* this could remove arguments. One participant reported that in their region there are currently investigations being undertaken into the conduct of drivers who have transported livestock that are suspected to be unfit to load. Again, it was recognised that it is difficult for a driver to push back and refuse to load an animal when the consignor argues there is nothing wrong with them. It was noted by one participant that this is currently a more common occurrence as cattle are worth so much money, but it is still only a small percentage of loads where this occurs (around 1%). Overall, participants would like to see those producers who are in the minority liable as opposed to the driver, and strongly believe at times the transporter is doing the right thing in terms of animal welfare as they are taking the beast to their final destination as opposed to leaving it to suffer on the property.

Could a Level 1 System help and how?

There is no benefit of a Level 1 system to alleviate conflicts between the consignor and transporter about whether animals are fit to load.

Could a Level 4 System help and how?

The Level 4 system would provide objective information using the GPS and accelerometer in the 'smart tag' to identify any animals which are potentially sick or injured and therefore not fit to load. Previous research has found that similar 'smart tag' technology has the ability to detect a number of common health and welfare issues of livestock including: lameness in sheep (Barwick et al. 2018) and cattle, lambing in sheep (Fogarty et al. 2020; Dobos et al., 2014), heat stress in cattle, predation (Manning et al., 2014) and disease (Falzon et al., 2013). This would alleviate conflicts between consignors and transporters as they could refer to the information provided by the smart tag to make a decision about whether an animal is fit to load.

- **Specific comments from participants about future systems**

One clear benefit of the objective information provided by the 'smart tag' is to alleviate conflict between consignors and transporters in deciding if an animal is 'fit to load'. Additionally, this information could be used to educate producers about common animal health and welfare issues. It was acknowledged by producer participants that the transporter is in a tough position and it is difficult to go against the consignor's wish to load an animal deemed not 'fit to load.' When discussing the decision process for whether an animal is fit to load, all participants agreed that this was done by visual inspection. This applied to both animals of poor temperament and those that were sick or injured. Furthermore, it was acknowledged that animals can be missed when only observing from one side. One participant stated '*It would probably help. If you had that information, I guess if there was a conflict...it's sort of both ways, the producer and the truck driver. It can work both ways. Sometimes the truck driver says he doesn't want to load because they're not fit to load, and then, of course, a conflict can arise then that that producer won't use that trucking company again and gets someone else*.' Another person continued on saying the data '...*could just substantiate the truck drivers claim to say that he wasn't prepared to load them because they were emancipated or weak and weren't fit to load or whatever.'* Ultimately, it is the transporters' responsibility to decide whether an animal is fit to load and they may be liable to prosecution under state or territory animal cruelty legislation.

Interestingly, another participant noted that the technology might also assist producers in understanding whether livestock were actually stressed or of poor temperament, even though they may appear so visually. The data might confirm based on data over a long period of time that the behavioural state of a particular animal is normal and therefore can be consigned. Other participants also highlighted that some of their grading reports have shown that animals which are considered of poor temperament, will always remain this way and the eating quality of the animal will not be affected. Conversely, anecdotal reports were given that an animal that is considered of good temperament, if stressed even slightly during the journey or whilst being handled before slaughter might lead to a poor-quality carcass. Whilst most participants could appreciate the potential benefits of a future 'smart tag', one participant struggled to see how the 'smart tag' would be better than their staff members who were all trained to pick up attributes such as illness and temperament. This highlights the need to educate producers and all those who work in the red meat sector, the capabilities of a future 'smart tag' and its ability to detect subtle behavioural and health issues before they are obvious to the naked eye.

- **Journey of livestock**

Whilst not common, transporters and the conditions during the journey are at times blamed for meat quality and animal welfare issues despite any proof they were responsible. This weakness of the current system highlights the lack of the lack of transparency across the supply chain and objective information available to increase accountability amongst consignors, transporters and receivers of livestock.

Currently, consignors have to trust that the transporter undertakes practices that maintain a high level of animal welfare during the journey (e.g. driving manner, spelling periods). When issues arise producers and processors can be *'... pretty quick to blame the trucks'*. *Even some of these big facilities like abattoirs and that, they're pretty quick to even blame us, but when you look at their own yards and they're pretty shabby sort of set up for a multimillion-dollar business*.' Currently it is difficult for transporters to avoid the blame being placed on them if the producer is unhappy with how animals are graded at the abattoir if they believe it is a result of transportation. Similarly, a tough journey during transportation to feedlots is often not realised until weeks after delivery when non-eaters or muscular issues are observed, highlighting the role transportation has on livestock production and welfare. Unnecessary time on trucks can have negative production implications when those animals are processed at the abattoir. There is an impact of a driver required to have a break to reduce fatigue and abide with fatigue/transport laws, and animals spending an extended period of time in the heat onboard a truck. The balance between animal welfare and driver fatigue is a reoccurring issue highlighted during consultation.

Could a Level 1 System help and how?

A Level 1 System could assist with tracking arrivals, departure and spelling times of animals but provides no quantification of the journey and how that may have contributed to animal welfare or carcasses grading poorly. However, as many large trucking companies already utilise GPS and other technologies (including g-force and braking sensors) which can provide at a minimum the information provided by a Level 1 system, implementation would have to be focused at owner-operators, smaller transport companies and producers who transport their own stock.

Could a Level 4 System help and how?

A Level 4 system could provide objective information to the consignor, transporter and processor about the behaviour state of the livestock whilst being transported. This would provide evidence that could be used to resolve disputes and address concerns about the lack of transparency across the supply chain. Deployment of a future 'smart tag' on livestock would enable producers to monitor their animals during the journey (using the GPS and accelerometer sensors) remotely, improving their confidence in the transport sector and help to resolve any discrepancies between an animal arriving at its final destination injured or dead, or grading poorly when processed.

- **Specific comments from participants about future systems**

Participants identified that the 'smart tags' would be especially 'useful down the track, absolutely...[for] conflict or dispute resolution'. Producers recognised the benefits of a 'smart tag' in providing information on what happens during the journey from their property to the saleyard or abattoir as '...another good tool to use to check [on] how the animals are going' to objectively verify the transporters account of events. Additionally, the time animals spent on the truck, when/if they were spelled or if they didn't travel well. Unnecessary time on trucks can have negative production implications when those animals are processed at the abattoir. There is an 'impact of a truck driver deciding to pull up for lunch in the middle of summer and spending an hour and a half with the cattle sitting on the side of the road…I usually track that through meat colours the next morning.' Whilst producers can get access to grading information (or meat colours as the participant discussed), there is an inability to verify who along the journey was responsible for ungradable animals or discounts imposed at the abattoir. The level 4 system would be able to identify at which point livestock experience stress or injury and provide information that is currently not available to verify events. On the other hand, disputes have arisen around whether drivers have spelled livestock appropriately 'we've been accused over the years that our driver has not pulled up from start to finish and checked his livestock. And we can always go into our tracker and show exactly where he stops and how long he stopped for.' This information can also be used by transport companies to discipline employees if they haven't followed correct procedure, 'and if we do have that incidence where the driver did go from A to B and that is proven…we will then issue the driver with a nonconformance or a warning letter. Or if he's been a problem to us, we'll dismiss the driver.' Access to this information or a level 4 system would be beneficial for the producer and processor, but concern was raised from a truck driver's perspective as things that shouldn't happen, inevitably do and how it could be used against them. For example, at times when the animals aren't travelling well a driver might make the call that it is better to push through and get to the final destination. However, this has legal implications for the driver as the law is clear on what is acceptable, putting the driver and transport company at risk. This participant said they felt these decisions were always made in the best interests of the animal.

Furthermore, participants believed that the information provided by the 'smart tag' could assist if something happens during transit. The loss of animals during transport is rare, occurring less than 1% of the time as advised by one participant, and the technology will not be able to prevent this, however it can provide objective information to verify at what point in the journey death occurred, and whether a pre-existing condition was present. This objective data on the timeline of events will assist in conflict resolution, accountability and improving animal welfare outcomes across the supply chain.

- **Trucking companies using technology**

One key theme that emerged through the consultations that is worth highlighting is that large trucking companies are increasingly investing in technology that is attached to their fleets and monitors driver behaviour. All transport companies reiterated the difficulty in balancing animal welfare, driver fatigue and the relevant laws.

Participants from two large livestock transport companies detailed the installation of 'seeing machines' on their trucks and how this technology is being used to improve driver welfare and fatigue management. This technology is a combination of sensors, cameras, vibration machine and alerts that monitors driver behaviour in real time (Guardian, 2020). This is in addition to tablets, mobile and satellite phones all providing opportunities to communicate with operations and access to company policy, procedures and permits. Although some information is not constantly monitored, if required it can be reviewed if an issue or dispute arises. They acknowledged that not all livestock transport companies, especially smaller owner-operator enterprises and primary producers with their own trucks will not be able to purchase such advanced and expensive equipment. The two large trucking companies consulted with spend a lot of money on the initial start-up cost of the technology and ongoing subscriptions, '*but it does cost us a lot of money to have it, you can understand, four to five SIM cards in every truck, there's 90 trucks here*.'

Driver safety is paramount with one participant noting since the implementation of driver fatigue technology, *'... we haven't had a serious incident since putting it in. But it's hard to know. We could be just having a good run, or not. We believe we have saved a rollover with it*.' However, it was also recognised that at some point technology saturation will occur and the tools and systems in place to protect drivers and other road users also have the potential to be distracting and cause accidents. Additionally, one participant highlighted the need to limit access to the information collected by these technologies as it can be highly sensitive and it is imperative to protect the privacy of employees. Technology currently employed by large transporting companies, '*hope our customers see this as a guarantee that [we] are trying [our] hardest to protect them in the chain of responsibility*.'

Whilst large livestock transport companies are increasingly investing in technology which has benefits for both driver safety and animal welfare, a large proportion of the trucks used to cart livestock are small owner-operator businesses or producers themselves. These smaller operators do not have the same level of technology incorporated into their business, and they are unlikely to do so in the near future. This also highlights a weakness in the current system, with the quality of trucks and trailers used during transportation and the demeanour of drivers varying greatly. One producer reported that they cart their livestock themselves the majority of the time and if they can't, will only use one other carrier who they deem to have a modern truck, good crate and be an honest operator. Another participant acknowledged that some transporters had trucks and trailers that were not up to standard that could cause animal welfare issues. Participants did recognise the issues faced in transporting livestock that are out of their control e.g. traffic lights and busy roads which require frequent stops and starts, causing stress both to the driver and the animal. Regardless, when considering any new technology to be adopted by the transporting sector it needs to account for the advanced, large livestock companies who already incorporate some of the latest advancements all the way to the smaller trucking companies and occasionally low, quality trucks used.