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Animal health diagnostic technologies - scoping study

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Abstract

The aim of this scoping study was to identify potential technologies and commercially available products that have the capacity to detect and locate shy feeders and ill-health in a feedlot environment. The study included technologies and products from cattle-related backgrounds, from other agricultural and livestock fields, and from areas completely unrelated, including those developed for the monitoring of humans.

Nearly 40 products and systems were identified and assessed. The following essential criteria were used to determine the utility of the reviewed products/systems, resulting in a suitable system capable of:

- Early detection of ill-health or shy feeding individuals,
- Locating the sick or shy individual animal within the feedlot,
- Meeting all environmental suitability criteria, and
- Costing < $8 per head if reusable, but preferably < $4 per head (based on discussions with feedlot managers).

This scoping study suggests that few technologies and products in their current form can be an effective system for deployment in Australian feedlots. That said, all of the technologies or systems that have been reviewed would require re-deployment of monitoring devices on multiple animals in order to meet the cost criteria. The greater potential for re-use will therefore decrease the cost-per head.

Executive Summary

There are approximately 450 accredited beef cattle feedlots in Australia. While rates of illness and death in feedlots are low, it is acknowledged that some animals have trouble adjusting to the feedlot environment, which can result in shy feeding and illness. Bovine Respiratory Disease (BRD) accounts for 50-90% of all ill-health and death seen in Australian feedlot cattle. With death rates up to 5% reported, BRD costs the Australian beef industry approximately $60 million per year, due to costs associated with treatment, reduced performance, wasted feed and cattle deaths.

There are obvious gains to be made with regard to early detection of sick or underperforming animals. While pen riders are responsible for identifying sick animals and shy feeders within feedlots, research has shown that monitoring technologies are capable of detecting these problems several days earlier than the symptoms are visible to pen riders.

The aim of this scoping study is to identify potential technologies and commercially available products that have the capacity to detect and locate shy feeders and ill-health in a feedlot environment. The study included technologies and products from cattle-related backgrounds, from other agricultural and livestock fields, and from areas completely unrelated, including those developed for the monitoring of humans.

The technologies and products identified to detect and locate shy feeders and ill-health in a feedlot environment were grouped into three classes: “behavioural monitoring technologies”; “diagnostic technologies”; and “animal locating technologies”. A further four classes were also investigated: “genetic diagnosis”, “blood diagnosis”, “clinical scoring systems” and “technologies from non-agricultural industries”. An overview of each technology and the associated products or systems is provided, including installation requirements, environmental suitability, cost, and current stage of development.

Nearly 40 products and systems are identified and assessed. The following essential criteria were used to determine the utility of the reviewed products/systems, resulting in a suitable system capable of:

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- Meeting all environmental suitability criteria, and
- Costing < $8 per head if reusable, but preferably < $4 per head (based on discussions with feedlot managers).

Suggestions are also made regarding the potential for the development of new systems. In finalising the study, input was sought from feedlot managers and staff, and veterinarians that consult to the industry. A site visit was also undertaken to Jindalee Feedlot.

This scoping study suggests that few technologies and products in their current form can be an effective system for deployment in Australian feedlots. That said, all of the technologies or systems that have been reviewed would require re-deployment of monitoring devices on multiple animals in order to meet the cost criteria. The greater potential for re-use will therefore decrease the cost-per head.

There is potential merit in using in-appetence as the primary method for detecting ill-health and shy feeding animals. It is likely that a simple autonomous system would be more appropriate for this problem than an elaborate centralised monitoring system. Alternatively, products that measure core body temperature from the rumen are recommended, with less confidence in temperature measurement from the ear canal. However, the obvious issue

with employing a temperature-based alert system is that it is only relevant for detecting ill-health, not shy feeding. The advantage of having a system that detects in-appetence is that both ill-health and shy feeding will be reported, the latter of which may not be due to fever or disease. From discussions, the principle of detecting a broader range of animal health and behavioural issues is more important than only detecting fevers.

Finally, the ranked systems are presented in the context of investment and time to market. In order to provide meaningful and useful information regarding the reviewed technologies and products, these have been divided into two classes: requires no or minimal investment, and available in short-term (1-2 years); or requires substantial investment and time for development (>2 years).

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1 Background

1.1 Introduction

There are approximately 450 accredited beef cattle feedlots in Australia (ALFA 2014). Although most feedlot cattle spend 85-90% of their lives on pasture, they are taken to feedlots to be grain-fed so that the industry can consistently supply market requirements of quality and quantity or when drought affects pasture conditions.

While rates of illness and death in feedlots are low, it is acknowledged that some animals have trouble adjusting to the feedlot environment, which can result in shy feeding and illness. Pen riders are responsible for identifying sick animals and shy feeders within feedlots. However, research has shown that monitoring technologies are capable of detecting these problems several days earlier than the symptoms are visible to pen riders. Inappetence is a symptom of both illness and shy feeding, whereas the other common means of identifying ill-health is an elevated temperature.

There are obvious gains to be made with regard to early detection of sick or underperforming animals. This scoping study was commissioned to explore the potential technologies and systems available to assist pen riders to make informed and timely decisions regarding moving animals to hospital pens.

1.2 Bovine Respiratory Disease

Bovine Respiratory Disease (BRD) accounts for 50-90% of all ill-health and death seen in Australian feedlot cattle. Generally presenting in the first four weeks following entry into a feedlot, BRD results from a combination of stress and infectious agents (both viral and bacterial). With death rates up to 5% reported, BRD costs the Australian beef industry approximately $60 million per year, due to costs associated with treatment, reduced performance, wasted feed and cattle deaths (MLA 2014 a and b).

BRD manifests in numerous ways in cattle, depending on the age of the animal, causative organism(s) and stage of the disease, among other factors (Currin and Whittier 2014, Merck 2014, Zoetis 2014). While identifying sick cattle is not an exact science, early clinical signs include:

- Fever - the connection between BRD and fever (40-42^{o}C) is strong. BRD is one of the most common causes of fever, and fever is one of the earliest signs of the BRD complex. To negate the effects of ambient conditions, temperature should be investigated in the early morning. Also a symptom of heat loading.
- Serous nasal and eye discharge - one of the earliest indicators of BRD, this form of discharge is watery, sticky and clear. Serous discharge usually starts from the nose, and then moves to the eyes as the disease progresses.
- Depression - affected animals hang their heads, look lethargic and either stand away from other cattle, or hide in behind other cattle.
- Inappetence - an animal's unwillingness to eat is tied closely to fever and depression. A "floppy" belly, caused by a shortage of fibre in the digestive tract, is an early sign of inappetence. Also a symptom of heat loading.
- Soft coughing - in early BRD cases, the lungs and airways are generally painful, so the animal will try to clear the airway with mild, tentative coughing. Loud, prominent coughing or "honking" indicates far more chronic, advanced cases, at which point treatment is difficult.

- Rapid, shallow breathing - more blood is distributed to the infected portion of the lungs, causing occlusion of airflow. The animal has to breathe harder to get good air exchange, because parts of its lungs are not working properly. The best time to evaluate breathing is in the early morning when environmental conditions are reasonably benign. Increased respiration when the environmental temperature is high may be caused more by the external environment than disease. Also a symptom of heat loading.
- Stiff gait - sick animals may experience muscle and joint soreness due to an increased systemic endotoxin load. Their movement indicates overall pain.
- Crusty muzzle - because it is not feeling well, the animal will tend to lick its hair and muzzle less and generally take less care of itself. At the same time, mild dehydration will cause a drying of membranes around the mouth, adding to the dry, crusty appearance.
- Salivation - the animal's overall feeling of malaise may cause it to drool and gape more than usual.
- Mild diarrhoea - endotoxins in the animal's system cause displacement of body fluids, dumping more fluid into the bowel and disrupting normal absorption of food, causing loose stools.
- Purulent nasal discharge - an indicator of more advanced BRD, this discharge is thick, cloudy and pus-filled. The cloudy appearance is caused by white blood cells that have localised in the respiratory tract to attack the infection.
- Bloody nasal discharge - also in acute BRD cases, blood may appear in the nasal discharge due to irritation in the respiratory tract. The protective mucosal lining is broken down and enters the respiratory system, where it is blown out.

Whilst prevention of BRD is preferable, early detection will improve feedlot productivity, profitability and animal welfare. Subsequent control of BRD will lead to reduced feedlot illness and mortalities, and faster recovery times for infected cattle (MLA 2014b).

2 Objectives

This report provides a thorough researched scoping study of current and potential technologies and systems that are capable of remotely and autonomously identifying an individual sick or non-eating animal within a feedlot pen, through assessment of:

1. The full range of potential technologies that have application in this area.

2. Current commercially available systems, plus systems under development that show future potential.

3. The practical implementation of the technologies in a feedlot environment, including installation requirements, ability to cope with environmental conditions, dust, proximity to cattle, data storage and processing requirements, etc.

4. The relative benefits and costs associated with use and implementation of a particular technology or system.

5. The current stage of development of the identified technologies/systems, likely time to market, and potential for strategic industry investment.

3 Methodology

3.1 Identifying potential technologies and products

Initially, technologies and products, both currently available and under development, were collated. These included technologies and products from cattle-related backgrounds, from other agricultural and livestock fields, and from areas completely unrelated, including those developed for the monitoring of humans. Where a technology was not deemed suitable to meet the objectives of this study, products were not investigated.

This scoping study was undertaken in May/June 2014. Information was sourced from:
- Online research
- Visitation of feedlots and discussion with feedlot managers
- Observation of and discussion with feedlot managers and a pen rider supervisor
- Discussion with veterinarians, both livestock and wildlife
- Discussion with animal nutritionists

Every effort has been made to provide accurate information, with the information provided being ‘best available’ on the day it was collected.

3.2 Review of technologies and products

A description is provided for each technology and associated product(s), including how it works (data capture, storage and delivery, components), its availability/stage of development, likely cost, environmental suitability, and capability in its current form. Environmental suitability was reviewed against the following criteria:

- Robust/able to be located away from cattle
- Non-corrosive
- Dust-proof
- Temperature tolerant
- Water-proof

Capability in current form was determined based on the premise that there are two separate elements to the problem of expediting the identification of ill-health and shy feeders:
- Detecting the existence of ill-health or shy feeding individuals
- Locating the sick or shy individual animal within the feedlot

Accordingly, the current capability of the technologies/products in doing one or both of these is outlined. The suitable technologies and associated products are reviewed using the following classifications:
- Behavioural monitoring technologies,
- Diagnostic technologies, or
- Animal locating technologies.

3.3 Ranking of technologies and products

In order to provide useful information regarding the suitability of the reviewed technologies and products, the criteria below has been used. These are based on our knowledge of the topic, and from discussions with industry professionals, feedlot managers and staff, and veterinarians. A suitable system must be capable of:
- Early detection of ill-health or shy feeding individuals (principally via inappetence or temperature),
- Locating the sick or shy individual animal within the feedlot,

- Meeting all environmental suitability criteria, and
- Costing < $8 per head if reusable, but preferably < $4 per head

Technologies or products that satisfy the above criteria have been ranked based on the level of investment/time required to make them a deployable system. Two classes have been devised:

- Available in the short-term: requires no or minimal (1-2 years) investment and time for development.
- Available in the long-term: requires substantial investment and time (>2 years) for development.

4 Results

4.1 Behavioural monitoring technologies

The technologies and products that may be suitable for detecting shy feeders and ill-health in a feedlot environment are presented below.

4.1.1 RFID tag technology

Radio-frequency identification (RFID) allows for the automatic identification and tracking of objects via the wireless non-contact use of radio-frequency electromagnetic fields to transfer data. The system comprises three components: a scanning antenna; a transceiver with a decoder to interpret the data; and a transponder (the RFID tag) that has been programmed with information. RFID tags are used in many industries, including the automobile, pharmaceutical and, central to this report, the livestock industry.

The ability to trace livestock from property of birth to slaughter is crucial to the 'best practice' management of the agricultural industry. RFID tags help to manage and safeguard livestock in the food supply chain. The RFID tags suitable for livestock include transponders effective for bolus use, tags for subcutaneous placement (implants), and ear tags.

In Australia, the National Livestock Identification System (NLIS) was introduced in 1999 to enhance Australia's ability to track cattle during disease and food incidents. NLIS-accredited RFIDs contain microchips which are encoded to unique numbers that are linked to the property that the RFIDs were issued to. These are all stored on a national database, allowing cattle to be traced quickly. All cattle must be fitted with an NLIS device (either an ear tag or a rumen bolus/ear tag combination) (MLA 2014a).

Building on the requirement of all animals to carry an individual ID through an RFID tag, further technologies have been developed to assist in the management and monitoring of livestock. These have included the ability to record animal weights, food intake and water intake, and automatic drafting.

Products

GrowSafe Model 6000®

GrowSafe Systems (Canada) have developed two systems relevant to the beef industry – the GrowSafe Model 6000® monitors feed intake and behaviour, and the GrowSafe Beef™ monitors weight and water intake. These products are fully developed, available now and installed in active feedlots (Figure 1).

The technology offers real-time, continuous (every second) and automatic monitoring of individual animals. The platform non-invasively acquires data continuously from multiple biometric and environmental sensors deployed at the feedlot, and enables the large-scale acquisition of digital phenotypic data, with metadata describing individual animal behaviour, feeding regimes, growth conditions and environmental interaction. The collected data is transferred wirelessly to the feedlot data acquisition computer, providing the opportunity for analysis and modelling of traits such as feed efficiency, stress tolerance and disease.

Both systems are designed with a focus on animals that present at a feed or water trough (suspended on load cells). Animals are identified using multiple RFID readers (we assume NLIS tags would be suitable; the antennae is moulded directly in the rim of the trough), and their time at the station(s) is calculated based on readings taken every second. This is then correlated with the weight/load of the feed or water, measured at a resolution of 10 grams. The systems provide automated information and statistics via the internet, and they are hosted by the manufacturers' server. Automatic messaging to telephones, cellular phones, pagers and/or alarms by email can be enabled depending on requirements. These systems have methods to identify those animals that do not present at the trough. However, although the ID of the inappetent or non-drinking animal is provided to the manager or pen rider, there is no integrated way of locating the animal in the feedlot.

GrowSafe System's Co-CEO Alison Sunstrum has stated that the GrowSafe Model 6000® is aimed at seedstock producers to measure Residual Feed Intake (a genetic selection trait in livestock), and may not be the best product for sickness identification. Conversely, she believes the GrowSafe Beef™ may suit the needs of the project objective better as it is designed for increasing profitability, partly via early sickness detection. However, we believe that the GrowSafe Model 6000® would be more suitable than the GrowSafe Beef™, given it can capture inappetence information. The system can be inserted into the existing feed trough location, and is currently installed in feedlots ranging in size from 1,000 to 100,000 head.

GrowSafe provides customers with a "turnkey" service program under a technology usage agreement for an annual fee, which includes:

- Technology supply, equipment maintenance, remote trouble-shooting and training
- Analytical software and upgrades
- Real-time advanced feedlot analytics and custom decision support software based on site-specific production goals
- Application programming interfaces between existing feedlot technology

The cost of the product varies from US$6-US$12 per animal per feedlot stay, dependent upon how the technology is installed and what attributes or metrics the feedlot requires.

Figure 1 GrowSafe products installed in North American feedlots

Aleis (Allflex) system

This system was designed for research by Murdoch University into the sheep feedlot industry, and was installed in the Wellard's Feedlot (W.A.) approximately 10 years ago (Figure 2). The system uses an array of RFID readers for ear tags, mounted above the feed trough, and captures statistics such as duration at trough and consumption.

Current Allflex Australia P/L Market Development and Innovation Manager Pat Gunston confirms that the product is commercially available. However, there has been no uptake due to the cost of implementation – it is believed that this array cost close to $100,000. It appears that the system could be suitable in a cattle feedlot environment, with minor modifications, and could identify those animals that have not presented at a trough (by NLIS tag not being recorded). There is currently no integrated way of rapidly locating the inappetent animals in the feedlot.


Figure 2 Aleis system installed at Wellard's Feedlot, W.A. (images courtesy Pat Gunston)

CowView

Zebra Technologies Corporation and GEA Farm Technologies have recently developed CowView. Currently used in European dairies, the system records behavioural data such as time feeding, and walking distances, as well as abnormal behaviour that may indicate ill health, in real time. The data is fed into a system that can handle more than 1,000 individuals at any one time, and can be accessed through an application on a PC, tablet or smartphone. This system operates independently of the NLIS. CowView uses individual collars to track the location of each cow in a herd, to within an accuracy of 30cm through a system of receivers (Figure 3). This system detects animals that are not feeding, then the user can locate the animal by typing in its collar ID into the mobile app, and the location is provided on a map of the cattle pen (also see "animal locating technologies" section).

This product is not currently available in Australia. The device uses Ultra Wide Band (UWB) radio frequencies for integration of the application. However, use of the UWB (3.0 – 10.2 GHz) is not permitted in Australia. The manufacturer suggested that they could use RTLS technology ISO2730 WhereNet instead, but this is yet to be explored.

In a feedlot application, there would need to be an array of receivers mounted above the feed trough (the RFID tag is in the top of the collar). From the promotional video (http://www.youtube.com/watch?v=IF-a3qxBHZw&feature=player_embedded), it appears that the receivers can be several metres above the collars. However, it is uncertain whether they are built to withstand an unsheltered feedlot environment, as they are currently used in dairy sheds.

In the Dairy Industry in Europe, the manufacturer claims longevity of at least 7 years, and a pay back on investment within 2 years. It is not clear how comparable this is to the Australian feedlot industry.

Figure 3 CowView, developed by Zebra Technologies Corporation and GEA Farm Technologies

OptiReader

Optibrand offers a device to identify animals via retinal scans. It offers an, inexpensive system that can positively identify individual animals at a designated location. The OptiReader device is a combination handheld computer and digital video camera. It captures and stores an image of an animal's retinal vascular pattern in as little as 15 seconds while the animal is restrained in a squeeze chute or calf cradle. A GPS receiver within the device determines the latitude and longitude, along with a time and date stamp, for each record. RFID or bar-code readers can be connected wirelessly or through a USB port on the OptiReader. The OptiReader can take digital photographs of ear tags and link them to the tag number, retinal image and GPS stamp. Optibrand software is available to help manage data.

In order to detect inappetence, the device would need to be mounted onto the feed trough. However, the system is not intergrated with a means of locating the animal. This system would require a significant amount of redevelopment to operate within a feedlot environment (with regard to environmental suitability), and also to capture the information without restraining the animals.

4.1.2 Non-RFID tag behavioural alert systems

Silent Herdsman®

Developed in Scotland, Silent Herdsman® is a 24/7 health monitoring system, tracking a cow's activity via a wireless network. Originally designed for the dairy industry, it automatically detects changes in normal behaviour, particularly in relation to parturition and oestrous. The behavioural detection is via the Artificial Intelligence module, which processes data on the collar mounted activity monitor, and has the capability to capture only meaningful data for each individual. The data currently downloads when the cow enters the receiving area of the base station, located within the field or shed (Figure 4).

Silent Herdsman® is designed to accommodate all herd sizes, ranging into the 1000s. The system is based on predictive data analysis of data gathered by 3D movement sensors in the collars around the cow's neck and then wireless transmitted via an antenna station to the farm's PC where the decision can be made around insemination, changing eating habits, etc. (Figure 4). It basically detects behavioural changes, which indicates heat, rumination, etc. and could possibly indicate health alerts through changing feeding habits.

Figure 4 The Silent Herdsmen® unit

The system only transmits alerts, by text or email, when a change in behaviour is indicated. While these alerts represent activity patterns related to oestrous patterns, they are not confined to this, and as such could potentially be modified for the beef feedlot industry. The hardware is rugged and designed for harsh environments, whilst the software is easily upgraded using wireless re-programming. The key components to the system include a touch screen PC, the data-gathering base station and the quick-release collar. The problem with this system is that the data collection process is "black box", and thus how the behavioural data is derived cannot be explained. The precision of the information is also not stipulated, and as such may not be detailed enough to track movement around the feed bunk. Given the alerts are based on deviations from "normal" behaviour, these parameters would need to be provided, which in a feedlot environment, may be difficult to ascertain.

Cattle Sense®

Cattle Sense® has developed a solution for monitoring cattle herds in remote open pastures. The unit comprises a collar fitted with sensors, a transmitter, GPS and a solar panel for powering the unit. The collar is linked to herd management software via an intra-herd network hub collar with satellite link (Figure 5). The system provides daily status reports on nutritional balance, reproductive events and health events for individual cows, including alerts.

This is a system under development, and thus any details regarding how and what sensors are operational on the collar could not be obtained. The collar is a prototype, and its design is targeted toward un-monitored environments, hence the satellite-based information delivery. The use of an intra-herd hub means that only a proportion of the herd need to be monitored, and the data is then extrapolated for the entire herd. In a feedlot environment, every animal would require a collar, to enable them to be monitored individually, and subsequently located. However, the system would be expensive to set up, and ongoing satellite data costs would deem it unsuitable. As it has been developed for cattle, the robustness of the unit, including the solar panel, appears to be adequate, with the only concern being the excessive rubbing seen in animals with high ecto-parasite loads.

Figure 5 The prototype Cattle Sense® collar, complete with solar panel

CowAlert

IceRobotics have designed the IceTag and IceQube sensors. Using the IceQube sensor, CowAlert has been developed for the dairy industry to monitor activity and behaviour, providing accurate oestrous detection and alerts for health issues such as lameness. The sensors can be attached the rear leg of an animal. The data can be stored on the devices for up to 60 days, and is downloaded wirelessly. The IceTag and IceQube (Figure 6) sensors use a 3-axis accelerometer, which provide detailed information on standing, stepping and lying activities, lying-down analysis and the MotionIndex of the animal. The MotionIndex is a proprietary measure of the overall activity of the animal, as measured in three dimensions. The CowAlert system is available in the UK, Netherlands and Belgium.

Figure 6 The IceTag (left) and IceQube (right) sensors

Wireless data transfer is available using IceReader ® download station and IceTagAnalyser ® software. It is not clear whether the wireless downloading of data needs to be done within close proximity to each device, or could be done from a remote office.

In a feedlot application, the system could be used to record movement of individuals, or more importantly for BRD related depression, lack thereof. Similarly, pedometers are being trialled to monitor cattle movement in Nebraska, built on the theory that a sick animal will not move (T. Batterham *pers. comm.).* The movement information is transmitted to computer via radio-towers, where software maps the movement. While there appears to be a strong correlation between (lack of) movement and ill animals, there are significant infrastructure set-up costs involved. Also, depending on the environmental conditions, there may be an overall lack of movement in the herd, whereby the data would not detect the sick animals.

Data loggers, such as the HOBO®G logger pendant, have been used to register a cow's head position during grazing, along with standing and lying times. Similar to the products above, this unit is independent of the NLIS, and attaches to the animal via halter or leg strap. It could be used to record long stationary behaviour, however, there is uncertainty associated with the duration of immobility that could be symptomatic of ill-health in a feedlot situation.

4.1.3 Remote visual monitoring

Cameras

The use of camera traps in the study of wild animals has improved our understanding of their ecological relationships and population dynamics (O'Connell *et al.* 2011). In the livestock industry, they allow for remote monitoring of animal births, the monitoring of stock in yards, feed and water checks, gate monitoring, crop watching and live view of current weather conditions. Livestock cameras range from the simple camera trap designs from companies, such as *Scoutguard* and *Reconyx*, to more complex internet connected and solar powered systems (e.g. *Anso Web Camera Systems*) (Figure 7).

Figure 7 Camera available for livestock monitoring include simple designs such as the Reconyx (left) to the Anso web camera system (right)

<u>Products</u>

Harrington Systems Electronics are building on a system that already sends images via the Next G network (Figure 8) or satellite phone system, and are currently developing a system that will allow for a zoom function for ear tag identification. However, cameras are not going to be able to identify ill-health or shy feeders any quicker or effectively than a pen rider, given the camera data will need to be viewed in real time to be of any use, which requires personnel viewing data continuously. This technology is more suited to replacing pen riders, not complementing them.

Figure 8 Harrington System’s remote camera for the Next G network

<u>Imagery</u>

The use of thermal imaging to detect wildlife abundance has been used, with varying degrees of success, on a range of animal species, including walrus, deer, squirrels and cows (Boonstra et al. 1994, Havens & Sharp 1998, Haroldson et al. 2003, Burn et al. 2006). However, endothermic animals adjust their rate of metabolic heat production to equal the rate of heat loss. Conductance; the flow of heat from the body to the environment (or vice versa), is determined by an animal's behavioural adaptations and the efficiency of their insulation (fat, blubber and fur) (Watson 2004). The insulation of some animals may minimise heat loss, thus making the thermal differential between them and their environment difficult to detect (Boonstra et al, 1994). As insulation is increased, heat loss is minimised (Watson 2004), making it difficult to identify certain animals via thermal imagery, and certainly negating the ability to identify and locate individual animals.

Satellite imagery on its own tells us little about animal behaviour. While studies have combined the use of GPS collars with satellite imagery to map animal movement, and subsequently better manage land degradation through over-grazing (Hardcock 2009), the application is not relevant here.

To be thorough, image recognition software to allow for identification of individuals, and whether this can detect any of the symptoms for early detection of ill-health or inappetence, was investigated. However, it is unlikely that this technology will ever be capable of identifying individual behaviour in a feedlot environment, let alone make the data available in real-time.

4.2 Diagnostic technologies

Technologies and associated products that may be suitable for detecting ill-health in a feedlot environment are presented below. These have focussed principally on measuring temperature and vital signs, as these are reportedly the earliest symptoms to be presented.

4.2.1 Temperature

Body temperature is an important parameter for assessing animal stress (Brown-Brandt et al. 2003). According to research, a cow must maintain its body temperature between 37.8^{o}C to 40.0^{o}C in order to sustain its physiological processes (Lukonge *et al.* 2014). The measurement of body temperature in cattle has been made from the rectum, ear (tympanic), vagina, reticulum-rumen and udder (milk), with rumen temperature demonstrated to be the most effective measure of core body temperature (Lukonge *et al.* 2014). The connection between BRD and fever (40-42^{o}C) is extremely strong. BRD is one of the most common causes of fever, and fever is one of the earliest clinical signs of the BRD complex, along with many other forms of illness.

Infra-red thermometers allow for temperature readings without the necessity of direct contact, and have been developed for a range of markets including human health, manufacturing, engineering and the environment. Many also come with a laser to ensure temperature readings are collected from precisely where they need to be. Compact enough for pen riders to carry in their pockets, infra-red thermometers could assist in the early detection of fever in cattle. The ability to monitor the temperature in feedlot cattle could also assist with the management of heat load (PIRSA 2006).

However, there are two principle issues with the currently available products, in relation to feedlot use. Firstly, the accuracy for these thermometers is ~2ºC, or +/-2%. For detection of fever in cattle, specifically in relation to BRD, thermometers would need to be accurate to <0.5ºC, and preferably 0.1ºC. Secondly, whilst infra-red thermometers do allow for temperature recordings without the thermometer touching the subject, they still need to be in close proximity, so a pen rider would still need to be close to the individual animal being assessed. In the summer months, recordings would need to be taken in the morning to avoid the effects of ambient temperature.

Products

Extech® Psychrometer

Forestry Suppliers carry a range of thermometers, including the Extech® Psychrometer (Figure 9). This robust unit includes an infra-red thermometer, is powered by a 9V battery, and includes Windows® compatible software. It will also record humidity. The distance to target ratio is high at 30:1, but as the distance from the object increases, the accuracy decreases.

Figure 9 The Extech® psychrometer with infrared thermometer

FeverTags

FeverTags LLC from Texas US, has developed an ear tag temperature reading device. It consists of a completely sealed external housing, and a “thermistor probe” that is installed into the ear canal (Figure 10). Temperature is measured every 15 minutes, to obtain an indication of typical temperature variations for the individual animal, and to identify elevated temperature before visual symptoms occur. Tympanic (ear) temperature and rectal temperature are very close, with tympanic temperature being slightly warmer due to the proximity to the animal’s hypothalamus (~0.02 ^{o}C difference). The device provides an alert when a reading is above 37.5 ^{0}C. The alert is an inbuilt illumination of ultra-bright light visible to the naked eye from ~13m, and of a certain colour to assist those with colour-blindness. Reportedly, the device will continue to flash until the temperature episode is reduced or the animal has been successfully treated and returns to normal. However, third-party reports suggest that the light does not turn off once the temperature again drops below the threshold. The light has no recorded impact on the animal, and has even been anecdotally reported to deter predators (coyotes and wolves in the US).

Figure 10 The FeverTags® temperature recording system

The device is designed to work on cattle >80kg, and ear type does not appear to affect how the device is installed or it's retention upon the ear. Cattle can experience ear drop when initially installed, due to the placement of the probe, but this is reported to improve with time. Whilst there were some reported cases of necrosis around the incision point, from lack of air circulation, in the early years, the design has been modified, and there have been no further reported cases of internal ear infection since. The FeverTags' probe is a specially designed device, also used as catheters in human medical treatments. The original probe was rigid at high durometer, but since 2012 FeverTags' probe engineering features have allowed the probe to relax and form to the inside of the ear canal, thus eliminating any pressure or stress associated with installation or use (at 40°C the probe basically relaxes much like a cooked noodle).

The device is used in dairy production, and remain on the animal for years. However, it can be used on multiple animals by simply removing and replacing the male clip. Battery life is ~180 days, and whilst the current model does not allow for battery replacement, the model due out later this year will.

FeverTags do not sell direct retail, purchase must be made through their distribution partners (in Queensland and Victoria), or your consulting vet/supplier anywhere around the globe. Typical retail price is around US$10-12 each, though most large volume customers receive discounts on volume. With multiple re-deployments possible with the 180 day battery life, this could equate to approx. $3-$4 per head. Currently, no price for the future replaceable battery is available, however, this is likely to further reduce the cost per head.

Agis CowManager SensOor

Agis Automatisering has recently developed a system to monitor temperature, activity and rumination – the Agis CowManager SensOor (Figure 11). Available in the Netherlands for dairy cattle, the basic model consists of an ear tag with a double temperature sensor (contact thermometer, no probe), but when combined with a collar and leg strap sensors, the system can also record movement specific to feeding, ruminating, and oestrus activity.

The ear tags can be attached to standard disk tags (but not the NLIS tag – management tags are no longer permitted to be combined with NLIS in Australia – MLA 2014a), or used as a separate management tag system with electronic ID (may need to be modified to allow programming of NLIS number).

They are reportedly reliable in the detection of diseases, including BRD, and have a battery life up to ten years. Data is provided via an on-site network of routers, internet hub and a PC. The routers (presumably Wi-Fi) need to be within 100m line of sight of the ear tags. If the SensOor is out of range, the data can be stored on the chip for several days. This is of no use in an early ill-health detection system. Alerts can be sent to a mobile device. However, once a problem has been identified, there is no integrated way of locating the individual. The accuracy of the thermometer is not reported, but as a contact thermometer it would be influenced by radiant air temperature. Cost is likely to be a limiting factor here, as each ear tag is from US$52, depending on quantity, and the routers are approximately US$650 each. There is a five year warranty with the product, and software module updates and a help desk.

Figure 11 The Agis CowManager SensOor clips onto the standard RFID tag

TempTrack®

Phase IV Engineering and DVM Systems have developed an automatic cow temperature monitoring system. The temperature sensor is embedded into an RFID bolus, and each bolus has a unique identification code that is the same as the animal's ear tag (for subsequent locating). Automatically measuring a cow's core temperature, the product provides for advance alerts of critical changes in temperature via SMS text or email.

There are two bolus design options, a passive one (no battery) that requires the animal to walk between RFID reader panels, and an active one (requires battery). The active bolus is relevant for a feedlot set-up, and logs the last 12 temperature readings and transmits data up to 91.4 m to a receiver.

The hardware consists of (Figure 12):

- Rumen boluses
- Receivers within water proof enclosures. Operates on either AC power (120 or 240 VAC) or solar (12 VDC).
- Base Station - obtains information from receivers and forwards information to a computer with TempTrack® software. Indoor and outdoor models are available.

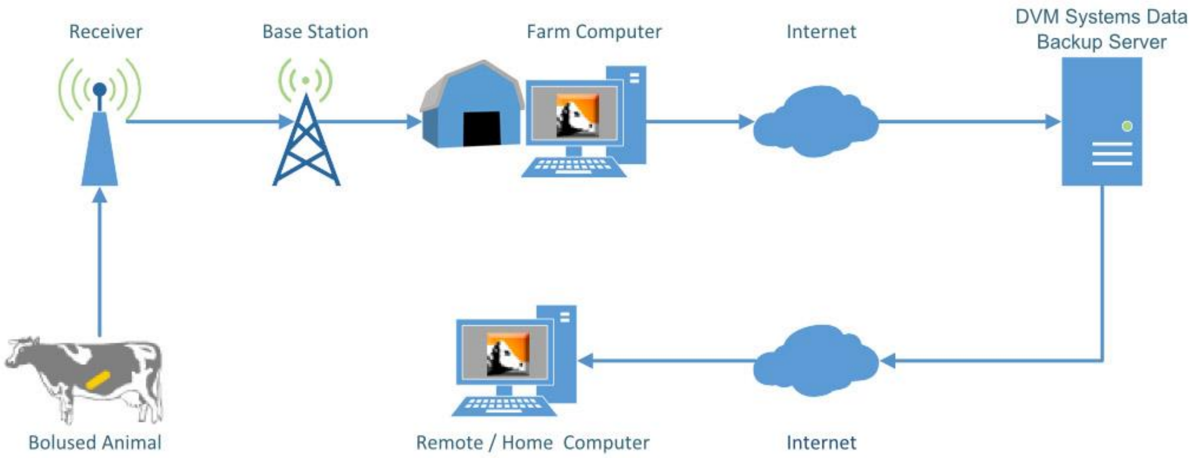

Figure 12 Diagram of TempTrack® system and hardware

The manufacturer explained that by negotiating a collection fee for the return of the boluses from the abattoir, it is possible to re-use the device multiple times. This product is available in Australia, however, both the manufacturer in the US, and distributer in WA, have avoided providing information pertaining to cost.

While there is currently no integrated means of locating the animal once it has been detected as having an elevated temperature, the existing link between the bolus and the ear tag ID could be expanded to include an illumination or other form of beacon for the pen riders. This depends on the base-level cost of each bolus, and is discussed further in section 5.2.

ABGI AllTraq System

Cattle Traq, renamed proprietary *ABGI AllTraq system* (American Biomedical Group Inc.) offers a bolus that transmits temperature information. The bolus (Figure 13) communicates with a series of antennas via RF Ultra Wide Band with a receiver and/or the animal's ear tag. The battery-powered tags transmit information at one-billionth of a second, with an expected battery life of four to five years on the animal. The bolus and ear tag have a coordinating 15-digit identification number specific to that animal. The antennas pick up the signal from the tags and calculate the location of the signal, transmitting the information back to a computer. The transmission distance is approximately 1km between antennas.

Various configurations are available that allow the bolus to record and transmit the animal's core body temperature, pH or internal gas pressure. An alarm will sound if the animal is acidotic or suffering from bloat. If an animal is sick, the appropriate data are transmitted to alert the producer's computer — or even light up the ear tag on the sick animal for quick sorting and doctoring.

This product is currently unavailable in Australia due to restrictions regarding the use of the UWB radio frequency spectrum. Presently, there is no confirmed product availability or pricing information.

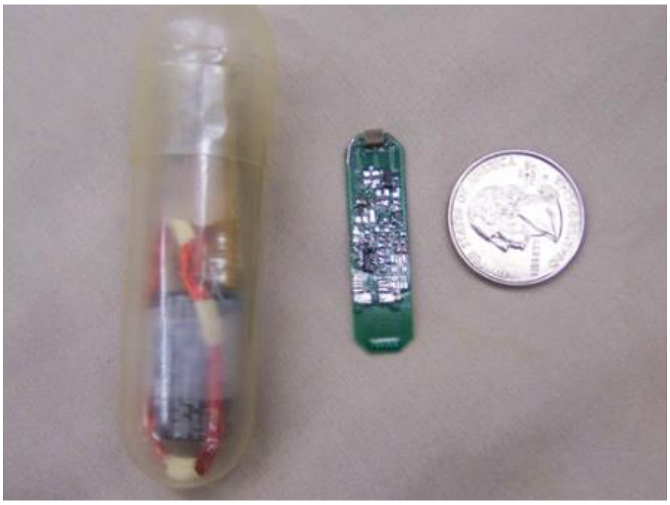

Figure 13 Demonstration bolus and circuit board

Human temperature measurement

True core temperature can only be measured by invasive means, with the use of thermometer into the oesophagus, pulmonary artery or urinary bladder, while non-invasive measures recorded from the rectum, oral cavity, axilla, temporal artery and external auditory canal are believed to provide the best estimation of core temperature (Pusnik and Miklavec 2009). It is only when thermoregulation begins to fail that heart rate and skin temperature correlate more directly with internal temperature, as environmental factors and a lack of insulating connective tissue influence temperature (M^{c}Callum and Higgins 2012).

Electrical (both analog and digital) and disposable chemical thermometers, developed for the recoding of human temperature to replace the mercury thermometer, still obtain the best recordings when placed under the tongue (Fogel'son *et al.* 1996). As such, these are not suitable for feedlot cattle.

The tympanic thermometer senses reflected infrared emissions from the ear membrane via a probe placed in the external auditory canal. It is reported to accurately estimate rapid fluctuations in core temperature as the tympanic membrane is close to the hypothalamus, though ear wax may reduce the accuracy of the readings. Temperature readings from here do not appear to be influenced by oral fluids, diet or environmental temperature. These benefits have been noted by the livestock industry, as tympanic thermometers have been developed for cattle (see FeverTags).
Temperature readings from the axilla are arguably unreliable as there are no main blood vessels in this region. Whilst rectal temperature is probably the most accurate method, this is

more time consuming than other methods. The temporal artery thermometer is held over the forehead and senses infrared emissions radiating from the skin. However, its reliability is not widely tested, and in a feedlot, is likely to be influenced by environmental factors.

An alternative innovation sees optical fibre Bragg grating (FBG)-based sensors integrated into textiles to measure the body temperature in humans (Li *et al.* 2012). Fibre Bragg gating sensors have recently demonstrated great advantage over electronic sensors in various fields, including health monitoring systems. The circuits of the sensor are woven into fabric upon manufacture. The temperature data can be picked up by a receiver, which can store information, and then provide it on the mobile phone, family personal computer or wrist monitors, in order to monitor the data in real time and send alerts. Intelligent clothing can monitor, process, store, and provide accurate data on human body temperature in real-time (Li *et al.* 2012). Again, this technology only measures skin surface temperature rather than core body temperature. Moreover, while the technology could in future be used for livestock collars, it is currently still experimental, with no timeline for development.

Sensirion produce two temperature sensors for consumer electronics, data loggers and thermostats. The STS21 is a fully calibrated digital temperature sensor, and claims high accuracy and low power consumption. The STSC1 is a similar product, though smaller. Similarly, it has low power consumption, a supply voltage of 1.8 volts and accuracy of +/- 0.3^{o}C. The SA1-RTD surface mount temperature sensor can be mounted on any flat or curved surface. The unit is accurate to +/-0.06% at 0^{o}C. However, external wires and a reading of skin surface temperature make it unsuitable for the cattle feedlot environment.

4.2.2 Measuring vital signs

There are four traditional vital signs - pulse, temperature, blood pressure and respiratory rate. As previously discussed, there are an emerging number of sensors suitable for measuring variables in animals. Further to this, there is an increasing market for sensors that measure the vital signs in animals as well, including heart rate and temperature, and more often than not, these also measure activity. Developed through the biomedical engineering and aged-care health sector, multi-component systems are able to measure breathing, glycaemic levels, oxygen levels, blood pressure and temperature. Fully integrated, these systems provide alerts when health conditions decline (Center for Technology and Aging 2010).

Products

There are a number of sensors developed for the equine market, measuring location, speed, heart rate and lameness (ETRAKKA®), heart rate, respiratory rate, temperature, blood pressure and movement (E-Nuntio®), and location and health, with automatic alarms (Equi-Safe®). However, these have largely been developed for use only when the horse is being worked, using a saddle blanket, and as such would require significant modification prior to any use in a feedlot situation.

Vital Signs DSP^{TM}

A number of software-defined medical devices have been developed for the human market. For example, LionsGate Technologies have utilised a proprietary analog-to-digital AC-coupled bridging framework, Vital Signs DSP^{TM} to connect inexpensive medical sensors to any mobile device through the universal audio port. This has reduced the need for purpose-built hand-held hardware for the measurement of each vital sign to compact smartphone-connected units and software-defined medical devices. For the smartphones to support the devices, they connect to the appropriate sensors to detect the body's vital signs via wireless, Bluetooth or cable tethering (Figure 14). However, similar to the products developed for the equine market, the system still requires sensors to be placed on the body, and as such may not be suitable for the feedlot environment.

Figure 14 LionsGate Technologies Vital Signs DSP™ (L-r, blood pressure, oximeter, thermometer)

Connect RCM

Care Innovations have developed the Connect RCM, a cloud-based application allowing patients to collect and transmit daily biometric data measurements from their own home to their clinician. However, similar to other human health monitoring systems, it requires sensors to be temporarily attached to the body, which is not feasible in a feedlot environment.

4.3 Genetic diagnosis

The development of DNA tests to enable the selection of animals resistant to BRD, and the incorporation of this trait into breeding will greatly reduce animal mortality and economic losses to the beef feedlot industry (Van Eenennaam 2012). Ongoing research in the United States indicates that disease resistance in cattle is a heritable trait. Trials at Colorado State University estimate an approximate 17% heritability when looking at whether or not a calf was treated for BRD. This increases to 24% when focus is on the animals pulled from the pen and treated for any reason, indicating that there is some genetic difference in the animal's ability to cope with the pathogen-associated and environmental challenges associated with a feedlot (Beef® 2011).

Several research groups are working together on the Bovine Respiratory Disease Complex (BRDC) Coordinated Agricultural Project (CAP), with the aim of using genetic selection tools to find genetic approaches to select for cattle less susceptible to this disease complex. The project is now in its fourth year, and has tested 2,000 dairy calves and 2,000 feedlot animals to determine whether genetic differences exist. The next step is to validate the findings using another 2,000 animals from different geographic locations, in the hope the research leads to genetic tests that can identify animals either resistant or susceptible to BRD (Beef® 2013). However, this technology is some way off, with no prediction of when the industry may be able to select for cattle that are genetically resistant to pathogen-fuelled diseases. As such, it is not suitable for consideration by the Australian feedlot industry at this time.

4.4 Blood diagnosis

Molecular and biochemical diagnostic tests, such as PCR and culture on selective media, are available for ante mortem diagnosis of BRD. Besides requiring the physical collection of blood or tissue sample from the individual animal, these are currently prohibitively expensive and cannot provide results at the point of treatment (Cooper and Brodersen 2010).

4.5 Clinical scoring systems

With many ante-mortem diagnostic tools relying on expensive tools and specialised training, such as ultrasound and radiography (Masseau *et al.* 2008, Abutarbush *et al.* 2012), a number of clinical scoring systems have been devised to improve and standardise BRD identification as a useful tool for farmworkers, clinicians and researchers (Love *et al.* 2014). Whilst the majority of these have been developed for the dairy industry, Panciera and Confer (2010) developed DART (Depression, Appetite, Respiration and Temperature) to identify BRD in beef cattle held in feedlots.

However, without a reference test, the ability to accurately classify individuals as BRD positive or BRD negative is difficult (Love *et al.* 2014). Arguably, the clinical scoring system is not too dissimilar to the simple observation of animals by feedlot riders. However, it may provide an objective check-list of applicable symptoms to systematically evaluate any individual that appears ill upon initial inspection.

4.6 Animal locating technologies

Locating an individual animal of health concern within a feedlot environment is potentially a difficult task. Here, technologies and products that could be used to locate an animal within a herd are presented.

<u>Products</u>

GPS tracking devices

Historically used for tracking wildlife, GPS tracking allows for the remote observation of relatively fine-scale movements in animals using the Global Positioning System and optional environmental sensors, automated data-retrieval technologies and a range of analytical software tools. In recent years, tracking collars have been used to better manage farms by monitoring the movement of livestock throughout the landscape, plotting the grazing patterns and in determining where livestock have impacted the soil. Generally, for cattle, GPS trackers would be attached to the animal via a collar or leg strap.

There are a number of companies that design and manufacture GPS tracking collars for a range of animal species (e.g. Animal Tracking, Lotek, Biotrack - Figure 15). While each GPS tracking unit is individually attributed to a different animal, these are not directly identified through the NLIS. Furthermore, the high-frequency sample rate required for a feedlot would quickly diminish the battery life of a satellite or NextG/GSM collar. However, one advantage of these products is that they are designed and manufactured for animal use, and as such are water-tight, and largely indestructible.

Figure 15 GPS collars used for the tracking of large animals

Moreover, the current GPS network limits the application of these collars in a feedlot environment as the accuracy of the GPS data is +/- 10 metres, thus not accurate enough to track behavioural information such as visiting a feed bunk. However, the advent of the new GPS L5 frequency (just launched by the US) will see an increase in precision to sub-metre in the next two to three years. The L5 frequency further mitigates the effects of variable ionosphere signal delay errors. This enhanced signal design will see sub-metre accuracies in the tracking of animal movement in closed environments, thus being conducive to feedlot monitoring. GPS chips are also fast becoming less consumptive of battery power and we envisage that over the next three years, GPS power consumption will be under 15 milliamps, thus enabling GPS tracking to be used for monitoring animal behaviour in an enclosure with sufficient battery life to last 140 days or more. In the near future, not only will GPS technology be able to identify odd behaviour but it will also be able to provide pen riders with the location of the animal at any time.

Taggle Systems

Taggle Systems specialise in ear tags (Figure 16) for the wireless real-time tracking of cattle, emitting a radio signal which is recorded by a number of stationary receivers. The data is accessed via a web-page. The system is designed for remote paddock monitoring, whereby more than three antenna towers need to be erected to triangulate the positions. The tags are $20 each, with an estimated retention of one year (they are not reusable). The antennas are approximately $5000 each. This system could provide a means of locating an animal, however, because it transmits data and does not receive data, it would require a lot of modification to be integrated with a ‘behavioural monitoring technology’ or ‘diagnostic technology’.

Figure 16 The Taggle wireless tracking system

Cattle Sense®

As previously mentioned in the "behavioural monitoring technologies" section, Cattle Sense® has developed a solution for monitoring cattle herds in remote open pastures. The unit comprises a collar fitted with sensors, a transmitter, GPS and a solar panel for powering the unit. The collar is linked to herd management software via an intra-herd network hub collar with satellite link (Figure 5). The system provides daily status reports on nutritional balance, reproductive events and health events for individual cows, including alerts.
This is a system under development, and we were unable to obtain any details regarding how and what sensors are operational on the collar. The collar is a prototype, and its design is targeted toward un-monitored environments, hence the satellite-based information delivery. The use of an intra-herd hub means that only a proportion of the herd need to be monitored, and the data is then extrapolated for the entire herd. In a feedlot environment, every animal would require a collar, to enable them to be monitored individually, and subsequently located. However, the system would be expensive to set up, and ongoing satellite data costs would deem it unsuitable. While it has been developed for cattle, the robustness of the unit, particularly the solar panel, is of concern.

Zebra Technologies

As previously mentioned ("behavioural monitoring technologies") Zebra Technologies Corporation and GEA Farm Technologies have recently developed CowView. This system uses individual collars to track the location of each cow in a herd, to within an accuracy of 30cm through a system of receivers. The system also records behavioural data such as time feeding, and walking distances, as well as abnormal behaviour that may indicate ill health. The data is fed into a system that can handle more than 1,000 tags at any one time, and can be accessed through an application on a PC, tablet or smartphone. This system operates independently of the NLIS, and uses the UWB radiofrequency spectrum, which is not permitted in Australia.

4.7 Technologies from non-agricultural industries

For both a complete system, and components thereof, alternative ideas are presented. This information is based on in-house knowledge of communications and monitoring technology, and interviews with feedlot managers and staff. These systems have good potential in feedlots for detecting inappetence.

Bluetooth/high-frequency passive systems

The simplest, low-cost system that could easily be developed uses either point transmitters (e.g. iBeacon below), or a wire transmitter (fed through PVC tubing that runs above or along the inside of the feed bunk). Both these systems transmit a weak signal. A receiver could be developed either as a collar or an ear tag (the male tag), which detects the signal when the animal is within 30cm of the bunk. The elegance of this system is that any number of ear tags/collars could receive the signal simultaneously and autonomously. The integrated tag/collar would then emit a buzzer or light signal when the animal has not been to the feed bunk for a pre-determined length of time over, say a 12 hour period. The tags or collars could be reusable and should be able to be developed for under $10. The PVC casing for the wire is likely to cost less than $200, based on equivalent systems on the market. This will easily transmit along lengths of wire of up to 200 metres. This alternative approach eliminates having a series of point transmitters, instead offering a low-power signal along the full length of trough or railing. AgriKnowledge has recently conducted some tests of a trial system procured and found it can be set to a low enough power setting such that the collar or ear tag needs to be within 30cm before the tag detects the animal is likely to be eating or drinking at a trough. While there is no guarantee they are actually eating, if configured correctly, this type of system holds the most promise at the lowest cost of being able to detect inappetence.

However, further R & D would be required to:

- Simplify the circuit and housing in order to further reduce costs.
- Test battery longevity to ensure life for multiple re-deployments (this is still dependent on the number of times the alert is triggered).
- Determine what an abattoir could or could not do regarding retrieval of the collar/ear tag.

Secondary developments to this system could include a wireless link to a mobile device or database, Bluetooth to a rumen temperature system, and an alert logger, with subsequent management actions through a Wi-Fi system.

Individual components/products of interest

The following products have been identified as having the potential to be incorporated in a system, with some modification and integration.

iBeacon

iBeacon is a low-powered, low-cost Bluetooth transmitter (<$ 20 each bought in bulk) that currently operates as an indoor or outdoor proximity system for advertising on iPhones in shopping centres and cafes. The technology enables an iOS device (or any Bluetooth receiving chip) to receive “push notifications” in close proximity to the beacon. The iBeacon uses Bluetooth low energy proximity sensing and transmits a unique identifier every 2 seconds.

In the context of a feedlot environment, multiple iBeacons would need to be set up along a trough that each emit continuous signals (lasting for 3 years on a small battery according to the manufacturer). The ear tags or collars on the animals only receive these signals when they are close to the beacons. The ear tags or collars would then detect how long they have been in close proximity to the iBeacons and alert the pen-riders (lights, a buzzer or Wi-Fi) when an animal has not visited a trough within a certain period of time.

An improved approach to having multiple iBeacons, offered by other manufactures, involves a length of ordinary wire that acts as a low-powered transmission antenna along the entire length of feed trough railing (as explained above).

Guest pagers

Companies such as Long Range Systems (LRS) Australia, have wireless guest pagers that light up when paged. Designed for use to notify people, these robust units could be modified for use in a feedlot situation as it has unlimited range. Furthermore, the system can automatically be turned on and off, increasing battery life by up to 50%. While not being able to be integrated with an NLIS, they could possibly be attached to a collar or management tag. This would work when integrated with a product that can determine ill-health or inappetence (as described above), i.e. the pager provides a means of locating the animal.

AutoStrad™

The Port of Brisbane, through AutoStrad™ technology, uses radar and laser guidance technology to navigate straddles around the shipping yard, enabling free movement on a virtual computer-generated grid of weighpoints. These systems allow the machines to operate unmanned and to move and stack containers around the terminal with pinpoint accuracy. While the use of a laser and radar grid system to accurately locate cattle is possible, the cost of development and installation of such a system is likely to be prohibitive.

LifeTag

The marine safety industry also has human proximity devices. Raymarine have developed the LifeTag man overboard system, a wireless system which consists of a base station and a series of wireless tags. Each MOB system includes two LifeTags and a base station, though the system can be extended (at additional cost), to monitor up to 16 LifeTags. Larger boats may be covered by an additional base station (max. of 2 base stations). LifeTags are fitted with Velcro for attachment and an LED for status feedback. The unit is powered by replaceable CR2 Lithium batteries, with an expected battery life of one year (with over 2000 operational hours).

MOBi-lert

Also developed for the marine industry, the MOBi-lert transmitters, when fitted to a person, send a message to the base unit indicating it is active. If the transmitter comes into contact with the water, it activates an alarm. The active system constantly monitors the whereabouts of the transmitter, and higher-end models features ‘track-back’ screen that immediately appears on the MOBi-lert console to guide you back to where the wearer went overboard. The base model comes with two standard transmitters and retails for $895. It can be expanded to monitor up to six transmitters, at an additional $160 each. The higher end units, capable of monitoring up to 18 transmitters, start at $1250.

In both the above marine-related cases, in their current form, the small number of transmitters associated with each base station, along with the high cost, means these products are not suitable for the feedlot environment.

5 Discussion

This scoping study suggests that few technologies and products in their current form, can deliver on all of the criteria below, to be an effective system for deployment in Australian feedlots. The criteria set were:

- Early detection of ill-health or shy feeding individuals (inappetence will detect both, whereas fever will only be relevant for illness),
- Locating the sick or shy individual animal within the feedlot,
- Meeting all environmental suitability criteria, and
- Costing < $8 per head (if reusable) and <$4 per head preferably.

The cost per head value was based on discussions with feedlot managers. This is obviously a value that will vary between operations; however, the lowest cost target has been used as the criteria to ensure that the outcomes are applicable across different scales of operation. That said, all of the technologies or systems that have been reviewed would require re-deployment of monitoring devices on multiple animals in order to meet the cost criteria. The greater potential for re-use will therefore decrease the cost-per head.

5.1 Behavioural monitoring technologies

Most of the commercially available systems researched are primarily designed to increase farm productivity and efficiency. However, technology and product assessment, supported by the conversations had with feedlot managers, suggests that the complexity of these systems and associated infrastructure costs are excessive for the limited purpose of 1. detecting ill-health/shy feeders and, 2. locating individual animals. This is largely due to the use of complex centralised data collection, storage and communication processes. Centrally-controlled systems also have the added risk of system-wide failure. The use of receiver arrays or towers will also become redundant technology within the next 2 years, following the release of the new L5 GPS frequency. Where costs have been reported by suppliers, these appear to be prohibitive, and deem the systems unsuitable for a feedlot application. Many of the systems have been designed for dairy cattle, where production outputs and the investment per head versus longevity and life span of the animal is much greater than meat production.

There is potential merit in using in-appetence as the primary method for detecting ill-health and shy feeding animals. It is likely that a much simpler autonomous system would be more appropriate for this problem than an elaborate centralised monitoring system. The potential system presented in section 4.7 is likely to meet all of the criteria. An autonomous system such as this has all of the processing and decisions regarding behaviour/alerts controlled by the device on the animal. The benefits include minimal infrastructure, lower costs, and protection from system-wide failure associated with a centralised processing core and database.

5.2 Diagnostic technologies

Due to the reported inaccuracies associated with measuring body temperature, products that measure core body temperature from the rumen are recommended, with less confidence in temperature measurement from the ear canal due to reported inaccuracies with the latter and the potential of the ear devices falling out.

Despite this, *FeverTags* is the only product that generally satisfies all of the criteria in its current form. Although it has received some negative feedback regarding the first version of the product, and there appears to be some issue with the 'light-up' alert, its functionality and pricing make it ready for deployment. The manufacturer is committed to continual review and refinement of the technology through research. The completely autonomous nature of the data collection and delivery on the animal reduce the likelihood of problems associated with system-wide malfunctions or outages.

The *TempTrack®* bolus thermometer system is innovative and reportedly accurate and reliable. However, pricing information for this system has been difficult to obtain from the supplier. If the bolus is cost-competitive, it would be worthwhile investigating how this could be incorporated with an autonomous alert device, i.e. a collar or ear tag light. There are also issues associated with device retrieval at abattoirs that would have to be addressed (e.g. appropriate bounty prices – see section 5.4).

However, the obvious issue with employing a temperature-based alert system is that it is only relevant for detecting ill-health, not shy feeding. The advantage of having a system that detects in-appetence is that both ill-health and shy feeding will be reported, the latter of which may not be due to fever or disease. From discussions, the principle of detecting a broader range of animal health and behaviour issues is more important than only detecting fevers.

5.3 Animal locating technologies

As previously mentioned, the current means of locating an animal within a herd is infrastructure intensive (with elaborate receiver arrays and antennas) and expensive. It is expected these limitations will be overcome with the release of the L5 GPS frequency, as developers and manufacturers update their technology, but this is unlikely to be available and fully tested in the next 2 years.

5.4 Retrieval of monitoring devices

Discussions with feedlot managers and staff raised several other issues that need to be considered when evaluating autonomous products or systems. The process of attaching or deploying the monitoring or locating device (ear tag, collar or bolus) must be carried out as the animal enters the feedlot and when the management tag is fitted. However, the recovery of the device will more likely need to be carried out at the abattoir. This presents some issues regarding additional cost (i.e. a bounty system), as well as labour (i.e. cleaning the product for re-deployment). The costs used in this study do not incorporate a product recovery fee.

5.5 Recommendations for investment

In order to provide meaningful and useful information regarding the reviewed technologies and products, these have been ranked based on the level of investment/time required to make them a deployable system. Two classes have been devised:

- Available in the short-term: requires no or minimal (1-2 years) investment and time for development.

- Available in the long-term: requires substantial investment and time (>2 years) for development.

Based on the two classes, the ranked products/systems are provided below.

1 As mentioned above, *Fevertags* is deployable in its current form. The new version due out later in 2014 with a replaceable battery will see further cost-competiveness via greater re-deployment potential. However, the limit of this approach is that it is only going to detect ill-health, not shy feeders. Furthermore, there is some question

over the accuracy of temperatures recorded from the ear canal. Given shy feeding is an issue for productivity and efficiency, ideally the manufacturer should consider expanding the system to detect this as well.

2 As previously mentioned, in-appetence detection may have more utility because it picks up a wider variety of behavioural issues, beyond just illness detection. The development of a new inappetence detection system based on the suggested idea (i.e. a variation of IBeacon where a wire transmitter runs along the full length of the feed bunk and receivers in collars or ear tags detect trough inactivity) would be achievable within an 18 month timeframe because the technologies are already on the market. With mass production (say 250,000 tags) a <$4 cost per tag is possible.

While there is a small amount of R&D required, the current transmitters used for repelling unwanted animals and advertising on iPhones are already robust, tested in the harsh field environments and currently available on the market. The electronics on the ear tags are the only components that would need to be adapted for feedlot needs. Provided commercial suppliers were prepared to collaborate, this could be put to market quickly and cheaply if project managed correctly through an R&D investment.

For <$4 per tag, the tags would only light up or emit a buzzing sound to alert the pen rider of inappetence. For <$8, transmitting a Wi-Fi alert signal to mobile devices may be achievable but without a position.

This system could also be upgradable to receive a rumen temperature reading to add further robustness to the detection system. However, this is unlikely to be available for <$4 per tag.

3 The development of a GPS tracking system utilising the L5 GPS frequency for precision monitoring of inappetence (sub-metre precision) would be achievable within 3 years, but could be more expensive than option 2 above. However, in five years a <$4 per tag cost is possible using this technology, providing battery technology improves to be able to reach >140 day life cycles. The advantage of such a system is that it could not only include an autonomous inappetence alert system but it could also transmit a live position of the inappetent animal to a mobile device held by the pen rider. Tracking of animals between production and hospital pens could also be recorded remotely. The extended timeline here is related to the release of GPS chips capable of receiving the L5 GPS frequency.

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6.1 Company and product links

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http://www.authorstream.com/Presentation/Sharck-10689-High-Frequency-RFID-Jim-Burgess-high-frequency-rfid-jim-burgess-ppt-powerpoint/

Agis CowManager SensOor - https://www.cowmanager.com/documents/file/CowManagerSensOor.pdf

Aleis - http://www.aleis.com/

Animal Tracking - http://www.animaltracking.com.au/

Anso Web Camera Systems - http://webcamerasystems.com.au/info/livestock-camera-systems

Autostrad™ - http://www.portbris.com.au/news-media/port-of-brisbane-a-snapshot/a-modern-port

Biotrack - http://www.biotrack.co.uk/

Care Innovations - http://www.careinnovations.com/solutions/remote-care-management/

Cattle Sense® - http://www.israeltrade.org.au/wp-content/uploads/2012/09/Rosner-LTD.pdf

CowAlert - http://www.icerobotics.com/

CowView - http://www.wired.co.uk/news/archive/2013-05/10/cowview-system

DVM Systems - http://dvmsystems.com/beta7-1/products

E-Nuntio® - http://www.orionveterinary.com/monitoring.html

Equi-Safe® - http://www.equisafe-project.com/about-us/

ETRAKKA® - http://www.baldivisvet.com.au/wpcontent/uploads/2013/10/ETrakka_A4_Booklet.pdf

Fevertags - http://www.fevertags.com/#!__products

Forestry Supplies - http://www.forestry-suppliers.com

Gallaher Animal Management - http://www.gallagher.com.au/weigh_systems.aspx

GrandCare - http://www.grandcare.com/system.html#activity

GrowSafe Systems - http://www.growsafe.com/index.php

Harrington Systems Electronics - http://www.harringtonsystems.com.au/

HOBO®G logger pendant - http://www.onsetcomp.com/products/data-loggers/ua-004-64

iBeacon - http://en.m.wikipedia.org/wiki/IBeacon

LionsGate Technologies - http://www2.lgtmedical.com/LGT_WHITEPAPER.pdf

Long Range Systems (LRS) - http://www.lrsaustralia.com.au/

Lotek - http://www.lotek.com/

Myhalo - http://www.halomonitoring.com/

Precision Pastoral - http://www.nintione.com.au/precisionpastoral

Raymarine - http://www.raymarine.com.au/view/?id=157

Recognition software - http://www.di.ens.fr/willow/pdfscurrent/rodriguez11b.pdf; http://www.mikelrodriguez.com/crowd-analysis/

QuietCare - http://www.careinnovations.com/

Raymarine - http://www.raymarine.com.au/view/?id=715

Reconyx - http://www.reconyx.com/

SA1-RTD - http://www.omega.com/pptst/SA1-RTD.html

Scoutguard - http://www.scoutguard.com.au/

Silent Herdsman® - http://www.silentherdsman.com/index.html

SmartCane - http://www.cens.ucla.edu/~maxim/Publications/papers/PubBodyNets08.pdf

Taggle Systems - http://www.taggle.com.au/livestock.php