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Review of opportunities for feedlot induction automation

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Executive summary

Cattle arriving at a feedlot are guided into a 'crush' where a team of staff perform an 'induction' consisting of tasks like ear tagging, vaccinations and drenching on each animal. Automation can potentially enhance the labour efficiency and safety of induction, however an understanding is firstly required of the range of induction processes and amount of automation in feedlots in Australia.

A telephone survey was conducted of 16 large feedlots in Australia and identified that 1 in 4 feedlots had automation in 1-2 induction tasks outside of ear tag readers, weigh scales or pneumatic tools. Priority automation opportunity areas were identified as more efficient and safer cattle catching, reduction of needlestick and kick injury to staff, and more precise dosage of drenches, HGP and injections to animals.

A time motion analysis of induction teams at 7 large feedlots was conducted to determine the labour costs of individual induction tasks and to identify priority tasks for automation. Ear tagging and cattle catching were the most time consuming tasks for all 7 feedlots. On average, the equivalent of 1 labour unit was waiting across the induction team for the time the animal was in the crush, and the cattle catch was 24% of the time to induct one animal. The results suggest that up to 2 labour units could be reallocated to other parts of the feedlot via automation of induction processes.

Delays in processing were observed to be caused by intermittent motion of animals into the crush, and inconsistent immobilisation of animals, due to the high speed at which animals entered the crush. To achieve greatest benefit from automation requires investment in infrastructure that will achieve two aims:

1. Calm animal behaviour through establishing guiding pens that encourage voluntary motion of cattle in a smooth operation. The stage in the induction process where greatest inconsistent behaviour in cattle is found is on the approach to the crush. There is a solution in the form of conveyors that circumvent many of the issues, and a further solution is proposed in this report.
2. The means to automatically identify cattle at every stage needs to be put in place. In the future new technology, in the form of smart tools also embodying automation and robotic techniques technology, will be able to accurately record corresponding measurements and log the therapy applied. The ‘Internet of Things’ is the model that will reduce burden on operators in critical areas, such as the crush.

A review of commercial technologies indicated that already 50% of induction tools are approaching a stage of being able to link and integrate with the wider system, sharing and communicating data automatically, for example drenching guns that link to readings from the weigh scales in the crush. Taking account of financial savings of reduced labour, more efficient chemical application and reduced injury, and working from quotations and costs of equipment, the break-even point on the additional investment for automation is estimated to occur well within a period of 3 years.

Automation in the form of smart tools can harness other technologies that increase information gathered while reducing the number of measurement tasks. For example, the analysis of blood and DNA will, in the near future, offer potential for easier access to rapid results, over current induction processes.

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1 Background

When cattle arrive at a feedlot they undergo a process termed 'feedlot induction' or 'arrival processing'. Cattle are moved on-foot or by horse from holding pens, up a curved alleyway which enters a raceway to a processing 'chute' or 'crush'. At the chute a number of processes may be applied which include (but are not limited to) scanning of National Livestock Identifications Scheme (NLIS) tag, application of a visual tag, weighing, determination of dentition, breed and sex, application of injectables and hormonal growth promotants, drenching, pregnancy testing, trimming of excess tail hair, horn tipping and corresponding data entry.

Feedlot induction is a labour intensive and very physical process for new cattle after arrival at a feedlot. There is opportunity for robotic and automation technologies to reduce the labour requirement of feedlot induction, with additional potential benefits of higher throughput, reduced animal stress and maximised workplace safety. However, an understanding is firstly required of how many staff, their tasks and costs associated with current feedlot induction processes in the Australian feedlot industry, and what automation and robotic technologies are available and feasible to use for feedlot induction.

2 Project objectives

1. Determine the level of automation of individual processes of feedlot induction currently in operation in the Australian feedlot industry.
2. Determine the labour requirements, cost and efficiency of feedlot induction at Australian feedlots (both overall and segmented to individual tasks).
3. Conduct a technology screen for automation solutions to manual tasks
4. Report costs and feasibility of identified technology not currently utilised by the Australian feedlot industry, and if further R&D or prototype development is required to implement the technology into the induction process.

3 Methodology

3.1 Method for Objective 1: Determine feedlot induction processes and level of automation

Two levels of review were conducted, a Level 1 review and a Level 2 review. The output of the review was a survey report with (i) a list of feedlot induction processes; (ii) amount of automation for each feedlot induction process; and (iii) benchmarking of current feedlot interests in technology.

- Level 1 review (16 feedlots total): A survey instrument was developed and applied as a structured phone interview with relevant feedlot managers. A reference group consisting of 16 large feedlots (greater than 10,000 head) participated in the phone interviews.
- Level 2 review (7 feedlots total): A subset of 7 feedlots from the reference group was identified to conduct a Level 2 review. The Level 2 review consisted of site visits to feedlots in QLD and NSW, with each site visit being 5 days. Each site visit consisted of interviews with induction staff and observation of induction processes.

3.2 Method for Objective 2: Determine labour requirements, cost and efficiency of feedlot induction

The Level 1 and 2 reviews from Objective 1 were also applied to Objective 2. The output of the review was a survey report with a breakdown of the labour requirements, cost and efficiency of feedlot induction.

- Level 1 review (16 feedlots total): The survey instrument was used to obtain the number of feedlot induction staff, what they do, their pay rate, and amount of time per animal associated with feedlot induction processes, so as to calculate labour requirements, cost and efficiency.
- Level 2 review (7 feedlots total): The site visits were used to observe and document feedlot induction staff duties in minute detail, e.g. pull lever, press button, lift dosing gun. To assist in documentation of staff duties, cameras were installed to record induction processes for 5-day periods. Recorded video was reviewed by USQ-NCEA to enable additional, and non-obvious, detail to be identified.
- Financial information (e.g. spreadsheets) associated with feedlot induction were also sought from feedlots involved in the Level 2 review.

3.3 Method for Objective 3 & 4: Technology screen for automation solutions

A literature search of commercially available technologies and technology providers was performed for technologies that have potential application to automating feedlot induction processes. Technologies developed for livestock and other industries were investigated. Automation of small components or whole processes in feedlot induction were identified.

The applicability and feasibility of each technology to feedlot induction was identified based on its current state of development and cost. The output of the technology screen was a technology report.

4 Results

4.1 Objective 1: Determine feedlot induction processes and level of automation

4.1.1 List of feedlot induction processes

Induction tasks observed at the 7 feedlots in the Level 2 review, and the number of feedlots that performed the task, were: cattle catch (7); ear tagging (left and / or right ears) (7); data entry (7); dentition (7); bang tailing (5); backline (5); neck injections (4); nasal drench (4); HGP (3); oral drench (3);pregnancy testing (1); and ear injection (1). Refer to Figures 4 and 5 in Appendix A, Paper 2: 'Quantifying costs of cattle feedlot inductions: Part B - Time motion analysis of induction team tasks' for a graph with this data. Also refer to Table 2 of the same paper for a listing of what each task involves. DNA sampling was not observed at any of the site visits.

4.1.2 Amount of automation for each feedlot induction process

38% of feedlots had automation in 1-2 induction tasks outside of ear tag readers, weigh scales or pneumatic tools. The induction tasks with automation, and percentage of participating feedlots using automation, were: automatic backlining (13%); barcode scanner for ear tag (13%); remote control crush (6%); prefilled data in software (6%); and ultrasound pregnancy test (6%).The remaining induction tasks (e.g. dentition; bang tailing; HGP) (58% of tasks) were manual across participating feedlots. At the 7 feedlots in the Level 2 review, there were 6 instances of automation across an aggregated number of 54 induction tasks. Hence, 89% of instances of induction tasks had no automated features. In summary:

- Feedlots with at least one instance of automation (besides weight, RFID) = 38%
- Induction tasks with at least one instance of automated features = 42%
- Instances of induction tasks without automated features = 89%
- Instances of induction tasks without automated features, and not automated at any of the participating feedlots = 64%

4.1.3 Benchmarking of current feedlot interests in technology

Overall, 75% of participating feedlots suggested that automation to the cattle catch, drench, HGP, injections, dentition / mouthing, breed detection or pregnancy testing would improve induction tasks. The feedlot responses that indicate opportunities and interests in automation are documented in Table 5 in Appendix A, Paper 1 'Quantifying costs of cattle feedlot inductions: Part A - Telephone survey of feedlots'.

4.2 Objective 2: Determine labour requirements, cost and efficiency of feedlot induction

4.2.1 Calculation of labour requirements, cost and efficiency

As per Appendix A, Paper 1, the median labour scenario was a team of 4 staff inducting 370 cattle for 4 days per week, with inductions taking 5 hours per day. The median time per induction was calculated as 50 s, based on number of cattle processed and hours of processing per day. Respondents of the survey indicated that a time of 30 s was considered most acceptable for cattle processing time. The median calculated labour cost for induction was $66,500 per year, and $18,000 per staff member. Hence, induction automation that allows 2 staff to be reallocated to another part of the feedlot would equate to an induction cost saving of $36,000 per year.

4.2.2 Documentation of induction tasks and staff duties

Induction efficiency metrics calculated from the time motion analysis of each of the observation sites are reported in Table 3 in Appendix A, Paper 2. The time motion analysis identified that:

- induction time per animal ranged from 16.9 to 33.8 seconds;
- one job action (i.e. reach for tool, lift and apply to animal, replace tool) was on average 6.5 s;
- the time to catch the animal in the crush was typically 24% of the time to induct one animal;
- reaching for a tool was typically 16% of the time required for each task; and

- team members were typically waiting for 22% of the time the animal was in the crush, which equated to an average of 1 labour unit across the induction team.

The induction tasks that were performed at all 7 sites were ear tagging, cattle catch, data entry and mouthing. Ear tagging (20 s), cattle catch (13.8 s), HGP (10.6 s) and pregnancy testing (20 s) were top 5 most time consuming tasks for all feedlots that performed that task. Job actions that involved close proximity of staff to the ears and mouth of the animal (e.g. ear tags and mouthing) took 20% more time than job actions involving tools that enabled staff to be further from the animal (e.g. nasal or oral drench).

4.3 Objective 3 & 4: Technology screen for automation solutions

A Technology Report that details findings from the technology screen is provided in the Appendix. The technology screen identified that automated features could be incorporated into an additional 42% of induction tasks observed during the Level 2 review. HGP and mouthing were the only induction tasks observed in the Level 2 review that did not have commercially available technologies with automated features, i.e. 16% of induction tasks had no commercially-available technology with automated features.

- **Guides and pens:** turret gate with remote control ($34k); Banss crush with head restraint; Clipex 2000 Crush with catch sensors ($20k); actuated drafting gates
- **Managing animal identification and correlation with data:** database and management software; printable ear tag; bar code printer; bar code laser engraver ($10k).
- **Assessments and therapies**: power tail trimmer ($450); ultrasound for pregnancy testing ($4k); automated sprayers ($4k); drench gun ($1650); AutoMed ($1420); drench injector ($1650); weighing scales ($2500); tissue sampler loading apparatus; tissue sampler applicator.

5 Discussion

There is opportunity for automation to enhance the labour efficiency and safety of induction in Australian feedlots, primarily via automated dosage of animals, calmer flow and immobilisation of cattle, and reduced contact between staff and animals. Priority automation opportunity areas were identified as more efficient and safer cattle catching, reduction of needlestick and kick injury to staff, and more precise dosage of drenches, HGP and injections to animals. 1 in 4 feedlots had automation in 1-2 induction tasks outside of ear tag readers, weigh scales or pneumatic tools. There were no standardised crushes for feedlot induction, so automated technologies need to be robust to a range of cattle breeds and weight ranges. Induction labour costs indicate that induction automation which allows 2 staff to be reallocated to another part of the feedlot would equate to an induction cost saving of $36,000 per year.

Ear tagging and cattle catch were the most time consuming tasks for all 7 feedlots. On average, the equivalent of 1 labour unit was waiting across the induction team for the time the animal was in the crush, and the cattle catch was 24% of the time to induct one animal. Key contributors to delays in processing were restlessness in cattle and crush effectiveness. The results suggest that up to 2 labour units could be reallocated to other parts of the feedlot via automation of induction processes.

Potential causes of restlessness in cattle were that animals would become confused because the gates would be opening and shutting while they were approaching or entering the crush. Some of the races leading to the crush allowed too many animals in the queue prior to entering the crush causing them to climb over each other. Animals were observed to be less stressed when the animal spent less than 6 minutes in the induction shed, and 15-30 seconds in the crush.

Some crush models did not provide adequate restraint of the animal during induction. Animals would be caught in the crush with either their heads, or heads and necks, becoming jammed under the crush gates. Delays in processing were observed to be caused by the head scoop not being used so the animal's head was moving, or the crush and race being empty while animals were waiting at the start of the race.

Financial justification for the addition of automation technology in feedlot induction can be modelled by contrasting the difference between a non-automated system and an automated system utilising smart tools assumed as commercially available products. Already 50% of tools are approaching a stage of being able to link and integrate with the wider system, sharing and communicating data automatically. These are termed 'Smart tools’, e.g. ultrasound scanners, some drenching guns, injectors and scales. Taking account of financial savings of reduced labour, more efficient chemical application and reduced injury, and working from quotations and costs of equipment, the model demonstrates that the break-even point occurs well within a period of 3 years on the additional investment for automation (see Value Proposition in Appendix).

Further research is required to quantify other costs associated with induction, to enhance the precision of the value proposition for automation: e.g. chemical use efficiency; maintenance costs of induction facilities; and total value of existing induction infrastructure across various feedlots. Costs obtained in this project indicate a return on investment in 2-3 years for automated infrastructure. Further research is required to implement automated technologies at a demonstration site and enable evaluation of animal calming measures and 'Internet of Things' concepts for animal and tool management in feedlot induction,

5.1 Achievement of project objectives

5.1.1 Objective 1: Determine feedlot induction processes and level of automation

A telephone survey of 16 feedlots, and site visits to 7 feedlots, identified 12 induction tasks that were performed and that 89% of instances of induction tasks did not have automated features.

5.1.2 Objective 2: Determine labour requirements, cost and efficiency of feedlot induction

A telephone survey of 16 feedlots, and site visits to 7 feedlots, identified that the median labour scenario was a team of 4 staff inducting 370 cattle for 4 days per week, with inductions taking 5 hours per day, and that up to 2 labour units in the induction team could be reallocated to other tasks via automation of induction processes.

5.1.3 Objective 3& 4: Technology screen for automation solutions

The technology screen identified that products with automated features for cattle catching, on-the-fly printing of ear tags, weight-based dosage of drenches and vaccines, and DNA tissue sampling were commercially available with cost effective pricing.

6 Conclusions/recommendations

There is a positive value proposition to Automated Technology applied to a feedlot induction process. The leading contributory factors are:

- Enhanced staff safety
- Reduced animal injury
- Cost saving in deployment of medicines and vaccines with improved accuracy of dose and decreased inventory shrink
- Greater accuracy and consistency in assessment of animals leading to accurate treatment application and optimal responses for health, growth, quality assurance and marketing
- Improved efficiency of processing allowing labour reallocation
- Reduced staff skill requirements offering greater flexibility and effectiveness in staff deployment at feedlot induction.

There is great importance in reducing the burden on the operator. Automation technology needs to be designed to reduce the intensity of skill requirements in the task as it will lead to reduced intensity, fatigue, risk-taking and error over long working shifts. The benefit of reduced skill is also greater flexibility in staff deployment across the feedlot induction process and reduced training requirements. There can be easy opportunity to rotate tasks with consistent outcome, cover for leave or staff sickness, less concentration of staff at the critical measurement and therapy point (the crush). All data must be recorded and correlated with each animal automatically, and decisions on animal sorting can also be automatic.

To embrace greatest advantage in automation technology two important infrastructures need to be invested in. Putting these measures in place will empower advanced induction processes that are accurate, safe, efficient and able to adopt the benefit of new technology as it arises in the future.

1. Animal calming measures such as indicated in the literature with solutions that control animal vision in pens, smooth voluntary motion and avoiding intermittent motion.
2. A computer WiFi intranet system integrating animal identification, database, interaction with smart tools and pens, automated decisions, real-time progress on tasks and feedback to the operator.

For benchmarking purposes, there is advantage for the experimental set-up to be at a leading feedlot induction plant. Of high importance is to utilise the set-up to demonstrate advantage to feedlot operators and other supporting stake-holders, the advantage of animal calming to increase safety and consistency, the potential of smart tools to reduce burden on the operator and increased integrity of the system output.

7 Key messages

- 89% of instances of induction tasks are not currently automated, with the remaining 11% of tasks being semi-automated. The semi-automated tasks were automatic backlining, barcode scanning of new ear tags, remote control of the crush, prefilled data in software, and ultrasound pregnancy testing.
- Automated dosage of animals, calmer flow and immobilisation of cattle, and reduced contact between staff and animals were the top 3 processes that were identified by feedlots that could be improved, made faster, cheaper, safer and better quality.
- Ear tagging, pregnancy testing and immobilising the animal in the crush for safe application of treatments were the most time consuming processes during induction.
- Human operators were very fast at performing induction tasks, taking on average 6.5 seconds to pick up a tool, administer the tool to the correct location on a uniquely presented animal in the crush, and replacing the tool. Each person performed an average of 4 tasks on each animal in a space of 23.5 seconds, and in shifts of 3 to 10 hours per day.
- Delays in processing were observed to be caused by intermittent motion of animals into the crush, and inconsistent immobilisation of animals, due to the high speed at which animals entered the crush. Catching the animal in the crush was on average 24% of the time to induct 1 animal.
- Processes that required close proximity to the animal's head, for example ear tagging, took longer than other tasks and this led to induction team members typically waiting for 22% of the time the animal was in the crush, equivalent to an average of 1 labour unit across the induction team.
- Potential savings arise from more efficient application of chemical treatments to animals, using applicators that are linked to readings from the weigh scales in the crush. A review of commercial technologies indicated that already 50% of induction tools are approaching a stage of being able to link and integrate with the wider system, sharing and communicating data automatically.
- Taking account of financial savings of reduced labour, more efficient chemical application and reduced injury, and working from quotations and costs of equipment, the break-even point on the additional investment for automation is estimated to occur well within a period of 3 years.
- Other benefits of automation are the displacement of staff from manual working conditions, hence enabling reduced physical requirements and greater employee diversity, and calmer animals that enable more consistent and high quality induction processes.

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9 Appendix

9.1 Technical Report

The attached Technical Report contains:

- Technology report
- Papers with results from Level 1 and Level 2 reviews
- List of technology costs from technology screen
- Value proposition for automation

9.2 Metadata

The following metadata is attached in CSV file format:

- Telephone survey responses
- Time motion analysis data

9.1 Technical Report

The attached Technical Report contains:

- Technology report
- Papers with results from Level 1 and Level 2 reviews
- List of technology costs from technology screen
- Value proposition for automation

Summary

This report describes a technical evaluation of the potential of cost-effective automation in cattle feedlot induction. The work undertaken investigated processes at 16 feedlots within Australia through telephone surveys and on-site measurements and observations.

There is a positive value proposition to Automated Technology applied in feedlot induction processes. Leading contributory factors are:-

- Enhanced staff safety
- Reduced animal injury
- Cost saving in deployment of medicines and vaccines with improved accuracy of dose and decreased inventory shrink
- Greater accuracy and consistency in assessment of animals leading to accurate treatment application and optimal responses for health, growth, quality assurance and marketing
- Improved efficiency of processing allowing labour reallocation
- Reduced staff skill requirements offering greater flexibility and effectiveness in staff deployment at feedlot induction.

There is great benefit in reducing the burden on the operator. Automation technology needs to be applied to reduce pressure in the task as it will lead to reduced intensity, fatigue, risk-taking and error over long working shifts. The benefit of reduced skill is also greater flexibility in staff deployment across the feedlot induction process and reduced training requirements. This approach can simplify opportunity to rotate tasks with consistent outcome, cover for leave or staff sickness, less concentration of staff at the critical measurement and therapy point. (The Crush). All data needs to be recorded and correlated with each animal automatically to reduce error, and increase accuracy in decisions for automatic animal drafting.

Greatest advantage in automation technology will need investment in two important infrastructures:

1. Animal calming measures such as indicated in the literature with solutions that control animal vision in pens, smooth voluntary motion and avoiding intermittent motion.
2. A computer WI-FI intranet system integrating animal identification, database, interaction with smart tools and pens, automated decisions, real-time progress on tasks and feedback to the operator.

These measures will empower advanced induction processes that are accurate, safe, efficient and able to adopt the benefit of new technology as it arises in the future.

This report describes the feedlot process and the opportunity to improve through automation. The method of the investigation, observations and measurements obtained are discussed leading to an evaluation of the process and justification for improvement using automation technology. The results of a technology screen of currently available solutions is accompanied by near future possibilities currently in development.

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1. Objectives

The work set out to explore potential opportunity of greater automation technology applied in feedlot induction operations. To build the perspective on the need for automation and benefit, specific objectives have been undertaken:-

1. Determine the level of automation of individual processes of feedlot induction currently in operation in the Australian feedlot industry.
2. Determine the labour requirements, cost and efficiency of feedlot induction at Australian feedlots (both overall and segmented to individual tasks).
3. Conduct a technology screen for automation solutions to manual tasks
4. Report costs and feasibility of identified technology not currently utilised.

These have been considered in the contexts of process efficiency, accuracy, consistency and safety within a suitable range of value proposition. On-site measurements and observations were retrieved from 7 operational feedlot sites, following discussion with a wider reference group of 16 feedlots by phone. This has enabled the project to cast a nationwide perspective on automation needs, and recommend variations and opportunities in practice.

The report points to the need to introduce the latest techniques in animal calming measures, and greater integration of tools, techniques and methods applied across the overall induction process. This will require investment in supporting infrastructure of appropriate pens and guiding enclosures, WI-FI intranet supporting automated retrieval of data and introduction of smart-tools through the 'Internet of Things'. This move opposes a trend of isolated development of automation applied to individual steps in the process. Full benefit requires a unified approach.

2. Background

The Australian feedlot industry has its origin 70 years back, and has been a principal contributor to building a high value market in 'Marbled Beef'. Commercial lot feeding began in the 1960s with the advent of new export markets and the need to build standards to secure opportunity for the industry (Condon and Coombs 2014). With an influence on providing high value beef, its assurance to markets of reliable high quality produce is important. At the same time operating costs, safety, and maintaining herd health, while managing an intense throughput of beef cattle are matters of concern. Slaughtered grain-fed cattle through feedlots of Australia stood at nearly 1.1M head over the annual quarter to August 2017. This is up by 7.1% (Herbert and Holmes 2017).

The induction process to a feedlot is enabled through a series of pens and guides. Ideally these should be designed to encourage voluntary movement of cattle from the point of arrival through to the critical stage of measurement, screening, possibly therapies and vaccination. Decisions made at this stage are to either release cattle into the feedlot or to segregate pending further assessment and other processes.

Automation has been applied over the years within separate devices to support guiding and fixation of cattle for measurement and therapy. Herding cattle in a confined space is not a trivial task, and methods of measurement and logging information are currently labour intensive. Animal behaviour is inconsistent, with some animals particularly agitated by crowding, intermittent movement through the process. Design impediments in the format of some pens, race and crush do not encourage steady voluntary motion.

State of the art automation integrating with the activity of operators will offer significant benefit. An integrated set of semi-automated tools, automated data retrieval and some automated stages will offer robust operation and advantageous flexibility in staff deployment. Unsettled behaviour in animals reduces consistency in measurement and treatment application, and can place both operators and animals at risk of injury. Animal calming measures are of high priority consideration to avoid high cost implications in automation designed to accommodate significantly unsettled cattle.

3. The current process

Considering each stage of the feedlot induction process separately, this section provides a short description of the process and considerations applied. The more prominent opportunities to benefit from automation are indicated.

3.1 Feedlot induction workspace

The feedlot cattle induction processing facility is a key piece of infrastructure that needs to be designed and constructed considering, processing speed (i.e. head/hr or line speed), staff safety and animal welfare (Watts et al., 2016). To achieve self-feeding, specific placement fences and gates are designed to accommodate cattle physiology and psychology. Encouraging voluntary movement is advantageous as participation in the process prevents baulking (Grandin 2007), reduces potential injury to the animal and reduces risk for staff.

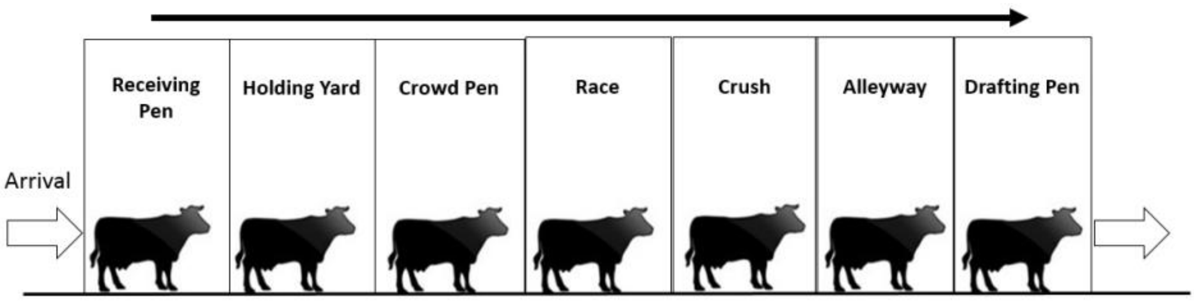

Figure 3.1 Stages of the feedlot induction process

Broadly, stages of the induction process are indicated in Figure3.1 and begin at the LOADING RAMP where the animals arrive, usually by truck. They are weighed as a group and enter RECEIVAL PENS where they are placed on feed and water. Here animal welfare consideration suggests a period for animals to relax and reduce stress to achieve a calm state before entering the intensive stages of induction. The animals are released into the HOLDING YARD. This pen encourages constant flow of a large number of cattle toward the CROWD PEN (Also referred to as Forcing Yard) that is designed to manage a small group at a time and channel the cattle into single file in the RACE.

The RACE enables controlled placement at the assessment stage. This assessment stage is often termed the 'CRUSH' where the animal is fixated to enable measurements and some minor therapy, such as vaccination, to be undertaken safely by staff, and without injury to the animal. Measurements at the CRUSH enable screening of the state of the animal. This assessment enables a decision on the animal.

The animal is then released into the ALLEYWAY and guided by gates to the corresponding DRAFTING PEN to segregate different groups, pending further assessment or process. Figure3.2 illustrates one possible configuration to control cattle.

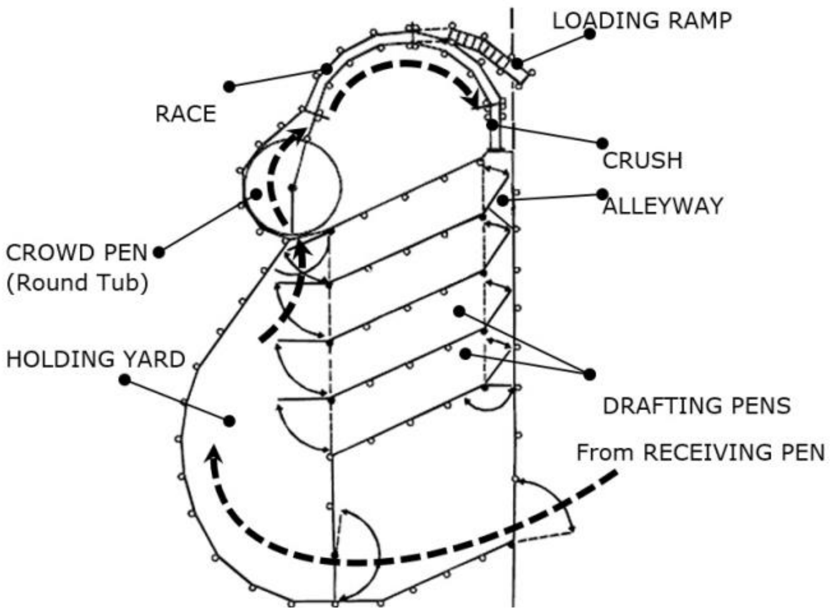

Figure 3.2 Schematic of a typical cattle processing facility.
(Linden and Halpin, 1994).

The aims of the stages are summarised as follows:

The *holding yard* design facilitates:-

- holding a large number of cattle;
- prevention of cattle bunching-up in corners to avoid slowing processing speed; and
- aligns the cattle in the desired direction of flow, encourages movement toward the crowd pen and reduces risk for intervening staff present in the pen.

The *crowd pen* design facilitates:-

- holding a small group of cattle;
- stress free, and smooth movement;
- adjusts cattle direction into the race; and
- non-return points on gates prevent cattle pushing back.

The *race* facilitates:-

- holding a small group of cattle in single file for individual assessment; and
- one-way gates and non-return gates separate sections within the race to ensure one-way motion.

The *crush* enables:-

- confining an individual animal;

- restraint to the body of an animal in a posture that is desirable for assessment and application of a treatment;
- restraint to the head and neck of the animal in a posture that is desirable for assessment and application of a treatment;
- rear access to the animal for tail banging, follicle sampling and pregnancy testing;
- access to the ears, neck and mouth of cattle for assessment and application of a treatment; and
- hydraulic controls to operate the squeeze, head-bail and crush gates.

3.2 Operation of the crush

The Crush is a key element of the induction process and the description here of its operation reinforces some of the issues observed at feedlots. Cattle entering the *crush* are first held in the *race* by non-return gates and encouraged to move forward on a clear visible path forward through the unit. This is achieved by opening the both the rear gate and head-bail, and lighting can be structured to accentuate the path (Grandin 2007). As a last resort to prompt movement reticent cattle are often prodded using a plastic element.

As the animal enters the crush it moves forward towards the space beyond the head bail. As the animal moves toward this position, the operator observes progress to anticipate the correct position within the confines of the crush, and controls the unit by activating the rear gate, head bail and squeeze functions. The crush rear gate is closed by either pneumatic or hydraulic actuation. As the animal approaches the head bail, the squeezing function of the crush gradually applies pressure to the sides of the animal to retard progress. Where motion is considered too great, the head bail can be partially closed to deter the animal. The operator then closes the head bail around the neck. The animal is then fixed in position. These actions require skilful co-ordination and timing by the operator to ensure that injury is avoided and the animal is positioned correctly.

Subsequent to assessment and required treatments, a decision is made on the next stage for the animal. The animal is released by retracting the squeeze panels and the head bail.

The overall principle of operation of different crush systems are similar. Example figures 3.3 and 3.4, after (Watts et al., 2016) and (Range Media, 2014) respectively illustrate the configuration. The former shows incorporation of an automatic ear tag reader, and the latter shows application of the chin scoop that controls the position of the head for operator access to ears, nose and mouth.

Figure 3.3: Cattle crush features. (Watts et al., 2016).

Figure 3.4: Animal held in the crush head-bail and chin scoop.(Range Media PTY Ltd 5/135 Margaret St, Toowoomba City QLD 4350).

4. Methodology

To meet the objectives of the investigation described in section 2, specific methods were adopted and are described in the sections below.

4.1. Method for Objective 1: Determine feedlot induction processes and level of automation

Two levels of review were conducted in a survey; a Level 1 review and a Level 2 review. The output of the survey describes (i) a list of feedlot induction processes; (ii) The current level of automation applied to each feedlot induction process; and (iii) benchmarking of current feedlot interests in technology. The results are described in section 5

Level 1 review (16 feedlots total): A survey instrument was developed and applied as a structured phone interview with relevant feedlot managers. A reference group consisting of 16 large feedlots (greater than 10,000 head) were identified to participate in phone interviews and are listed in Appendix 1.

Level 2 review (7 feedlots total): A subset of 7 feedlots from the reference group were identified to conduct a Level 2 review. The Level 2 review consisted site visits to feedlots in QLD and NSW, and each site visit being 5 days. During site visits information was retrieved through interviews with induction staff and observations of induction processes.

4.2. Method for Objective 2: Determine labour requirements, cost and efficiency of feedlot induction

The Level 1 and 2 reviews of Objective 1 were also applied to Objective 2. The output of the review describes a breakdown of labour requirements, the cost and efficiency of feedlot induction. The results are described in section 5.

Level 1 review (16 feedlots total): The survey instrument was used to obtain the number of feedlot induction staff, what they do, their rate of pay, and duration of time per animal associated with feedlot induction processes; this enabled labour requirements, cost and efficiency to be evaluated.

Level 2 review (7 feedlots total): Site visits were used to observe and document feedlot induction staff duties in minute detail, e.g. pull lever, press button, lift dosing gun. To assist in documentation of staff duties, cameras were installed to continuously record induction processes for 5-day periods. Longer-term remote monitoring was possible from USQ-NCEA facilities where required. Recorded video was reviewed by USQ-NCEA and feedlot staff to enable additional and, non-obvious, detail to be identified.

Financial information (e.g. spreadsheets) associated with feedlot induction were sought from feedlots involved in the Level 2 review.

4.3. Method for Objective 3 & 4: Technology screen for automation solutions

A literature search of commercially available technology and technology providers was performed for technology with potential benefit in the automation of feedlot induction processes. Technology to assist animal inspection; semi-autonomous with physical staff action; automated retrieval and record-keeping of digital data have been considered. The technology is described in section 6.

5. Results from Level 1 and Level 2 reviews

The results from the Level 1 and Level 2 Reviews are presented as papers in Appendix A. The abstracts of the papers are copied below.

5.1 Level 1 Review - abstract

Quantifying costs of cattle feedlot inductions: Part A - Telephone survey of feedlots

Cattle arriving at a feedlot are guided into a 'crush' where a team of staff perform an 'induction' consisting of tasks like ear tagging, vaccinations and drenching on each animal. Automation can potentially enhance the labour efficiency and safety of induction, however an understanding is firstly required of the range of induction processes and amount of automation in feedlots in Australia. A telephone survey was conducted of 16 large feedlots in Australia and identified that 1 in 4 feedlots had automation in 1-2 induction tasks outside of ear tag readers, weigh scales or pneumatic tools. Overall, 75% of participating feedlots suggested that automation to the cattle catch, drench, HGP, injections, dentition, breed detection or pregnancy testing would improve induction tasks. Priority automation opportunity areas were identified as more efficient and safer cattle catching, reduction of needlestick and kick injury to staff, and more precise dosage of drenches, HGP and injections to animals. Hence, it is concluded that there is opportunity for automation to enhance the labour efficiency and safety of induction in Australian feedlots.

5.2 Level 2 Review - Abstract

Quantifying costs of cattle feedlot inductions: Part B - Time motion analysis of induction team tasks

Cattle that arrive at a feedlot are guided into a 'crush' where a team of staff perform tasks like ear tagging, vaccinations and drenches, in a process called feedlot 'induction'. Feedlot induction is a key process in lotfeeding which has potential for labour and time savings via automation. A time motion analysis of induction teams at 7 large feedlots was conducted to determine the labour costs of individual induction tasks and to identify priority tasks for automation. Ear tagging and cattle catch were the most time consuming tasks for all 7 feedlots. On average, the equivalent of 1 labour unit was waiting across the induction team for the time the animal was in the crush, and the cattle catch was 24% of the time to induct one animal. The results suggest that up to 2 labour units could be reallocated to other parts of the feedlot via automation of induction processes.

6. Technology screen

Relevant technology and techniques to enhance automation

This section considers current technology that could be able to contribute toward automation in feedlot induction processes. It also points to new developments offering future opportunity. The section is divided into three categories:

- Section 6.1: Guides and pens for controlling movement and placement of cattle.
- Section 6.2: Technology automating identification, and management of data and decisions.
- Section 6.3: Tools and devices for measurement and therapies.

Together with a central computer and WIFI system much is currently possible and machine vision has a wider role to play in controlling guiding stages. Attempting integration of stages with automation will place the process ready for future enhancement as new technology evolves.

6.1. Guides and pens

Important infrastructure for automation needs to be in place to guide cattle in a calm process. The configuration of pens is important, and investment on this aspect will enhance working conditions for operators. Smart gates, curved pen sides, smart automated machine detection and surveillance to control smart gates and maintain a steady flow of animals can be achieved in an integrated semi-autonomous feedlot induction system. Each part of the guiding system and framework through the stages to organize and arrange cattle for the main tasks at the crush, and subsequently onward to the drafting pens need to be interconnected together as an integrated system of 'The Internet of Things'. This section considers techniques/ technology that can be applied as fixtures and in an autonomous/ semi-autonomous arrangement.

6.1.1 Crowd pen

Grandin and Johnson (2010) describe the benefit of curved tracks to guide cattle forwards and to limit the forward sight of cattle. Solid side-walls avoid visibility of activity outside the track or pen and obscure the presence of human operators. In figure 6.2 (Watts et al. 2013) shows one possible configuration for an induction process that follows the guidelines. Cattle enter at the gate, pass through the narrowing Catwalk and into the Forcing yard. Following single file into the race they pass through the crush and exit at drafting pens where they are segregated ready for the next stage. Not all Feedlot stations have embraced the calming factors fully.

Two critical stages to consider are the Crowd Pen (Forcing Yard) and Race leading up to the Crush. To avoid injury, the Crush is important to control carefully and precisely when restraining the animal. This is difficult to achieve where animals are agitated. Different existing designs are in use:-

The function of a Crowd pen can be implemented as the 'Bud-box', Figure 6.2. To operate effectively requires a skilled handler to be inside the box with cattle. This creates a Workplace Health and Safety hazard. The handler should be well trained and fully understand animal behaviour to avoid being caught in unsafe positions within the box. Safety walkthrough man-ways or man-gates could increase the safe operation of a bud box. Automatic or remote control operation of the swing gate in the bud box or a remote controlled or automatic robotic device to simulate the movement of a handler are possible innovations that could be developed.

Alternatively the curved crowd pen shown in Figure 6.3 is a safer option as operators are not required within the pen. The operator can move the crowd pen central pivoting gate from the catwalk. As the handler pushes the gate around the pen the cattle in front move into the race. Even though the catwalk position can minimise injury, during the survey there was an incident where an operator was kicked while on the catwalk. This indicates the level of risk to which operators are frequently exposed.

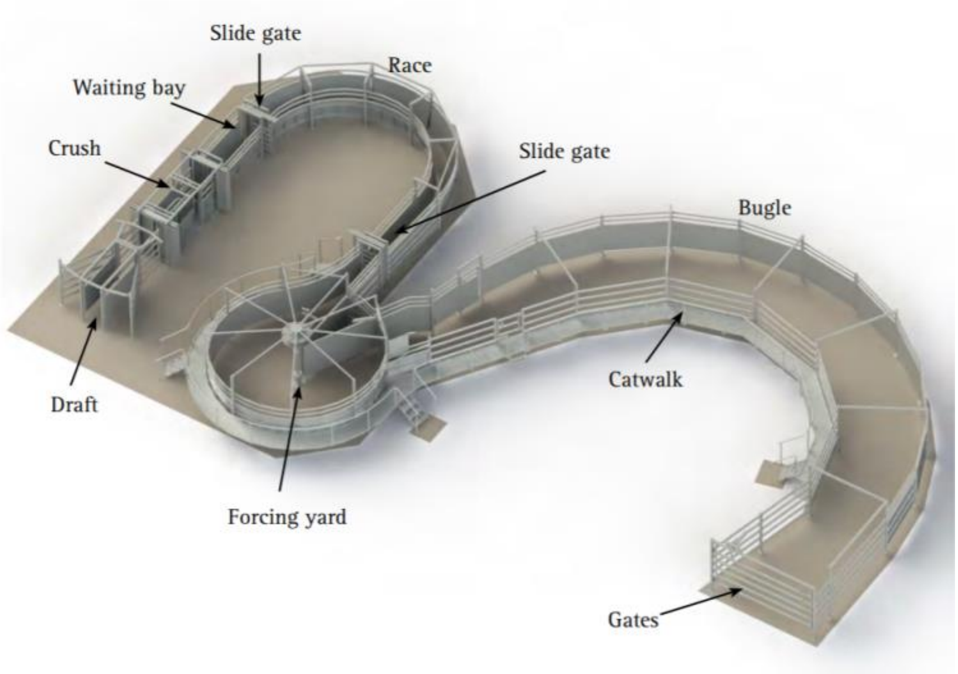

Figure 6.1 Schematic illustrating the curved catwalk, race. (Watts et al 2016)

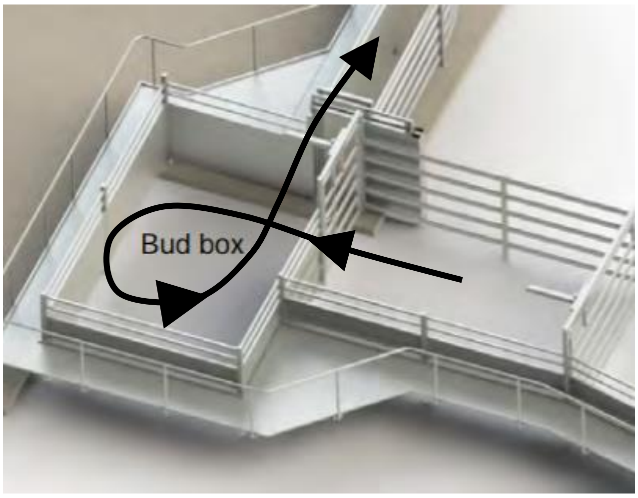

Figure 6.2 Illustration of a “Bud Williams” Bud box, after Davis and Janke (2016) - modified.

Figure 6.3 Curved tub configuration of a Crowd Pen. (Davis and Janke 2016)

An improvement can be sought through the application of a 'Turret gate' Figure 6.4. Turret gates are remotely controlled, driven by low pressure hydraulics and are available and can divide and sort animals. The gate can rotate (i.e. swing) and shuttle (i.e. slide) into open and closed positions Figure 6.5.

The typical base cost for a 9ft Turret Gate is from $34,205 that includes curved guide panels encircling the gate, a heavy duty 4 function remote and 3 phase power unit. 10ft modular connecting races can be purchased for $7,455 each. Installation not included.

Figure 6.4 Turret Gate (Courtesy ofCatagra Group,PO Box 3456, Caloundra, QLD 4551)

Figure 6.5 Automated turret. (Source: Youtube 2017; http://www.catagra.com) illustrating the rotating and shuttling motion of the gate.

6.1.2 Race and crush

The cattle crush is an important tool of the infrastructure of the induction process. It has the sole purpose of immobilising the animal in a position that is safe for both the cattle and induction staff. Successful and efficient operation depends on cattle arriving in consistently calm behaviour. Currently a skilled operator is needed to catch the animal in the correct position. As indicated in section 3.2, the difficulty in this task is exacerbated by agitated animals. A reluctant or agitated animal delays the task of correct positioning considerably.

The design of the Clipex 2000 is indicated as having successful automated operation. Current cattle crush control is performed either mechanically or by using pneumatic, or hydraulic solenoids controlled using manual switches. The Clipex 2000 Series cattle crush shown in figure 6.6 has sensors on the front and rear gates that detect the cattle as they pass through the crush and open and close gates accordingly. It is claimed that the crush can autonomously perform catching, weighing and drafting without the action of an operator. The head bail is required during cattle inductions but is not automated on the model shown.

A recent possibility is to adapt the stunning pen manufactured by Banss AG of Germany, Figure 6.7, that lifts the animal slightly to diminish force intensity that the animal can exert. The pen currently rotates to meet requirements of the slaughter line. A modification could provide a solution to arrest animal motion and operate within a feedlot induction process.

A further approach to be considered addresses calm conditions and automatic animal restraint. Grandin (2009) led the development of a conveyor system that is used known as the 'Centre-track restrainer'. It is used successfully to produce consistent conditions in an abattoir line Figure 6.8. Contrasting with the slaughter process, in feedlot induction there are many operations that can cause disturbance and sound from the animal. Nonetheless, one would expect greater consistency in presentation of the animal at a crush station as animals would be less mobile and calm without contact with the floor.

Figure 6.6 Clipex crush with autonomous catching.(Courtesy of Clipex, http://clipex.com.au/cattle-handling/cattle-crushes/2000-series-cattle-crush)

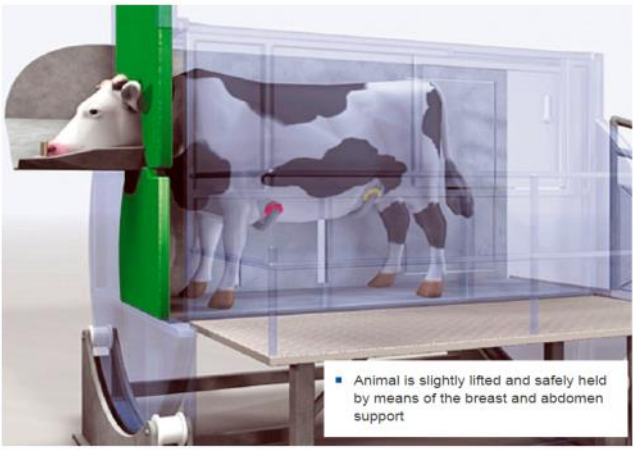

Figure 6.7 A crush facility used currently in slaughter lines manufactured by Banss of Germany (Banns AG 2017) (Courtesy of Bansshttp://www.banss.de/en/)

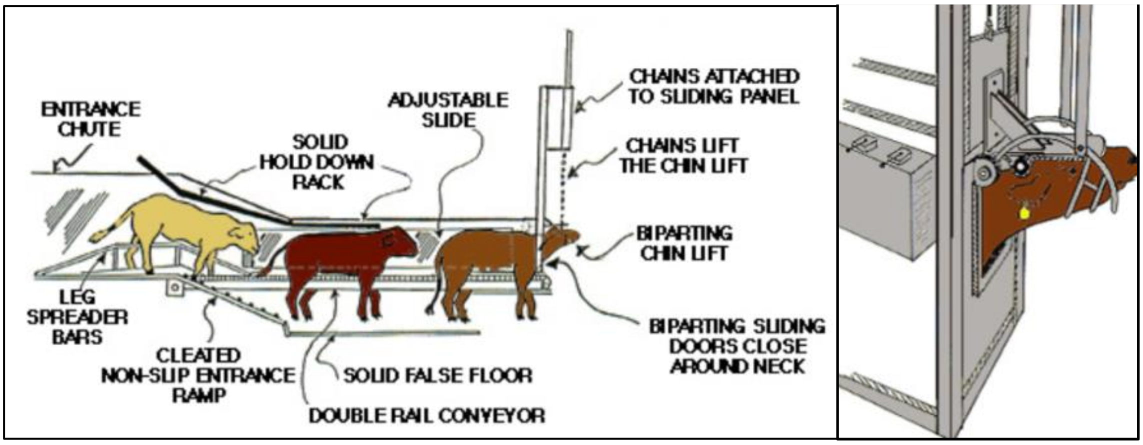

Figure 6.8 Schematic illustrating the configuration of a 'V' conveyor system to restrain and present cattle to the assessment point under calm conditions. (Grandin et al.2009)

Both V-track conveying systems and centre track conveyor systems have been adopted in some abattoirs in the USA, Canada and Australia. A study of 48 commercial slaughter plants found that thirteen plants (27%) utilised a centre track conveyor and six (13%) had a V conveyor for restraining cattle (Grandin, 2001). Of the abattoirs that had adopted a conveying system, the line speed ranged from 150 to 390 head per hour. This is significantly faster than the current speed of inductions performed in Australia at approximately 90-100 head per hour. The study also found that line-speed had little effect on cattle vocalisation indicating that conveyor speed was not a source of cattle discomfort in the process (Grandin, 2001). Some studies have found that the V-conveyor can cause stretching of the skin that damages blood vessels if the speed of the conveyors are not synchronised so the centre track method may be favourable (Grandin, 2010).

The performance of this system is worthy of benchmarking with respect to current systems for delivering cattle into a crush. The operational questions of reliable operation, relative cost of maintenance also need to be considered and contrasted with conventional approaches.

A further alternative is the adaption of a circular pen from equine applications, Figure 6.9. Cattle would enter as an alternative to the race in the induction process, Figure 6.10. Encouragement of ambulation around the pen can be achieved to produce continuous motion. This configuration offers potential for more than one crush to be arranged around the periphery. Cattle would then be guided into a holding pen, pending entry to a crush, by a diverting gate with little delay in ambulation and maintaining separation from the processing animal ahead.

Gates can be automatic with individual cattle observed/ detected by overhead machine vision. This alternative solution could be more easily adopted into existing feedlot induction processes and has potential to maintain calm operating conditions for the animal. This configuration would need to be constructed and trialed to contrast performance.

Figure 6.9 Circular pen encouraging animal mobility in equine applications.

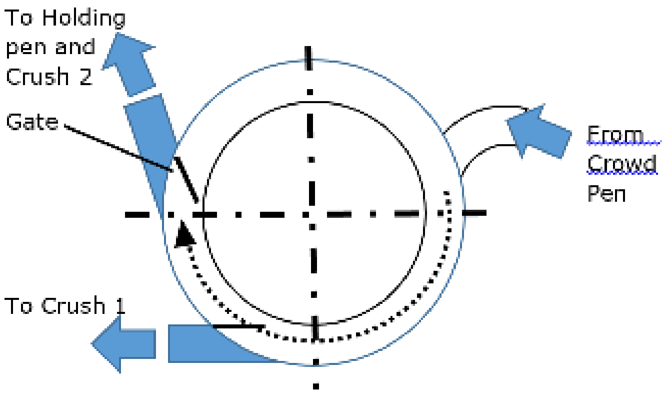

Figure 6.10 An alternative configuration for the race in an automated system

6.1.3 Smart gates

Smart gates for guiding cattle have been developed over a period for application in dairy and in supporting barn feed applications. These are gates actuated automatically, often from sensor signals relevant to the presence of an animal or completion of a stage in a process. Manual and automated triggered gates enable operators to maintain separation from animals. From the technical viewpoint, achieving correct cattle placement in a process in dairy poses similarity to controlling cattle movement in feedlot induction. Ear tag readers enable identification to be recorded and its progress in a process known. See for example the article entitled "cow traffic management system, DeLaval. http://www3.delaval.com/ImageVaultFiles/id_411/cf_5/Smart%20selection%20gate%20SSG.pdf

6.1.4 Drafting gates

Drafting is a management action performed following the Crush to group cattle requiring subsequent processes into pens via a multi-directional drafting gate. A skilled stockperson uses visual assessment and other assessment at the Crush to set the gate and assign each animal to the required pen. In an automated system this process could be performed automatically with the benefit of precise measurements that are retrieved automatically through operator deployed semi-automatic tools, or automatic measurements such as in weighing. An automated system can correlate measurements instantaneously.

Automatic drafters, Figure 6.11, consist of a confinement area such as a crush equipped with sensors to facilitate automatic detection of the presence of an animal and control of front and rear gates, weighing platform, and drafting gate. The system senses an animal approaching, opens the rear gates, detects when the animal is present on the scale, closes the rear gates, and weighs the animal, then opens the front gate and the drafting gate to the desired drafting pen. Automated drafting gates and guide gates can be integrated into an automated system solution for the drafting stage.

Figure 6.11: Example three-way drafting gate (Watts et al.2016)

6.2. Managing animal identification and correlation with data

Ear tagging has been used successfully with a variety of ear tags available. Australia's system for identification and tracking of livestock is NLIS (National Livestock Identification Scheme) and uses RFID devices. RFID ear tags are recognised by Low Frequency technology. 134.2Hz has been adopted internationally. Bar coded ear tags are an alternative, often supplementary tag. These have a permanent bar code printed at the point of application of the tag. In an automated plant, the integration of functions, animal identification and animal location is best achieved by using a central WIFI system connecting a central real-time database and automated tag readers at strategic points in the system.

Some feedlots apply supplementary tags using a barcode system that serves for in-house purposes. Ear tags with barcode identification can be printed or engraved. Figure 6.12 displays laser engraving which enables ear tags to be engraved on-the-fly at a rate of 2-3 seconds per tag.

To ensure accurate determination of data correlation with animals it is important that machines and measurement points are equipped to read the tag automatically. To avoid errors, manual data entry should not occur as information automatically retrieved can be automatically correlated with the animal in a central database. Similarly, where samples are extracted from the animal for further processing, these can be labelled automatically with the referenced barcode of the animal. These observations will increase the general integrity of the system.

A system benefitting from integrated automation technology can assist the operator. With intense operations at the 'Crush', operators can be presented with a specific list of tasks for the animal, an indication of tasks completed, decision points, and could be equipped with smart tools correlating measurements to animal groups and therapies automatically. Feedback is important to reduce burden and fatigue on operators working long shifts.

Figure 6.12 Laser engraving of eartags on a rotary stage. (Source: Youtube 2017)

Database software, tag writers and readers are available. The software will be extended in future enabling automatic extension to increased functions of the process. Smart tools can be expected to increase for a range of tasks too. The software will need to accommodate a standard protocol such that manufacturers of tools will be supplying devices that are integrated by simple means at the feedlot. One commonly used management program used amongst survey participants was StockaID (StockaID, ELynx PTY Ltd, 68-70 West Street, Toowoomba Qld 4350 Australia).

Within the survey it was found that while several participants used this management program, only one person had experience with automatic drafting gates. This indicated that either the drafting systems had not been integrated to full potential or the induction staff preference was to operate the drafting gate via manual remote control. The practical benefits of automatic drafting is best realised in an integrated system. It will be possible to minimise intermittent flow of cattle and achieve a smooth flow that is a recommendation for maintaining calm animal behaviour. The provision of automated retrieval of data and helpful feedback to the operator will enable focus on performing the tasks with reduced burden and fatigue. The impact can be reduced intensity in the task, reduced operator skill requirement and greater flexibility on staff deployment throughout the induction process.

6.3. Assessments and therapies

Measurement and therapies are undertaken by operators and require steadiness. Near fixation is achieved at the crush enables a range of processes to take place, and the sequence of operation and level of work for operators is intense. Safety for the operator and integrity of the work undertaken is critical. Long shifts with variable animal behaviour is a significant challenge for and likely to promote fatigue and error. Smart tools that reduce pressure and skill requirement, and that ease repetitive strain injury, will transform operations and improve the working environment.

In this section tools at the state-of-the-art are presented that offer these qualities. Looking to the future there will be further improvements supporting system integration, simplifying measurement tasks, combining measurement tasks, reducing off-site processing, increasing accuracy and consistency, and increased operator safety.

6.3.1 Tail banging/Tail trimming

'Tail banging' refers to the process of removing part of the switch of the tail to achieve conditions that will enhance the health of the animal. The Power Tail Trimmer TailWell2™ is a drill attachment that is used to trim the tail hair from cattle (Figure 6.13). Holding the hairy tail inside the circular attachment, the user activates the drill and pushes it up the tail removing tail-hair as it advances. It is claimed that this tool will trim a tail within 4 seconds. It will likely offer advantage in terms of operator safety. (TailWell2™-Power Tail Trimmer, Shoof International Ltd, Cambridge, New Zealand retails for $450).

Figure 6.13 TailWell2™ - Power Tail Trimmer drill attachment for trimming tails (Shoof International Ltd. New Zealand).

6.3.2 Pregnancy testing

The identification of pregnant heifers during induction is important to assign a management plan. Methods can vary, however the principal technology in current use relies on ultrasound scanning.8-10 weeks subsequent to mating, the operator searches for the pulse in the artery supplying the uterus, the presence of a calf's head and the uterus shape. The price of ultrasound scanners start at $4,000 with the Keebomed WED 3000 VET system that can be ordered with variety of scanner heads to serve the application and anatomy. The Repro Rectal probe of BOVISCAN Inc, US, figure 6.14 provides an advanced system. An ultrasonic probe is applied to generate an image of the heifer's uterus, displayed on a viewing screen. Feedback to the operator is the pregnancy assessment and estimate of calving date.

Figure 6.14: Repro Rectal Probe, OJO Goggles and ReproScan LCD Monitor 2.0 (ReproScan, 2017)

Looking ahead, in the near future, the possibility of using blood to determine pregnancy in feedlots could be considered. This will require the convergence of technologies described in section 6.3.4. The advantage of using blood is that results are absolute from an early stage in pregnancy, and will not require a skilled operator or veterinarian to administer the process and determine the result. It may be combined with other processes.

6.3.3 Drenching

The application of a fluid treatment for internal parasites and external parasites in cattle is known as 'Drenching'. The correct dose is specific to the weight of the animal. Under-dosing in chemical drenches can lead to an ineffective kill and chemical-resistance in the target species. In contrast, over-dosing an animal is wasteful in cost and may exaggerate side-effects. Drenches are applied either to the skin or orally. Treatments are for worms, lice, flies and ticks. The principal means of administering the treatment are by:

1. A Backline Drench (A line of drench medicine is poured along the back of the animal.)
2. An Oral Drench (A dose of medicine is sprayed orally.
3. Injection (Injections can be used to treat both internal and external parasites.)

Automated solutions to apply backline drenches to cattle have utilised the movement of the cattle through races to apply the drench medicine. McPhee and Hirst (1992) developed a system that applied the drench via a roller wicked with medicine as the body of animal pushed against it while passing through gates. Alternative delivery methods exploit cattle behaviour. Several manufactures provide basic systems consisting of rollers for cattle use to scratch or rub themselves to facilitate transfer of the drench chemical (Rol-Oyl - Livestock Oilers, Rol-Oyl, Lincoln, Nebraska, USA; Easy-Way Walkway Oilers, Easy Way, Decorah, Iowa, USA). Resistance to the drugs and other side effects result from not managing controlled individual doses.

Other automated drench sprayers are US based products. These are claimed for protection against mites, lice, ticks and flies, and drench an animal passing beneath a spray nozzle. Drenching occurs with the presence of the animal based on time of day and animal identification (Figure 6.15) :-

- **3D Quik Hand Sprayer** (3-D Cattle Equipment, LLC) – sprays over, sides and underneath animal.
- **'The Cow Sprayer'** (cowsprayer.com).
- **'Kattleguard Fly Control'** (Dairy Solutions, Inc) –This high pressure spray system applies an insecticide at high pressure in a fine mist. It has been designed for use with an insecticide that adheres to the outer fur of the animal. It is claimed that the approach avoids insecticides penetrating onto the skin of the animal, avoiding dermal irritation.

Figure 6.15 Automated spray systems from 3-D Cattle Equipment, cowsprayer.com and Dairy Solutions, Inc.

6.3.4 Drenching guns and injectors

Oral and injection drench application systems that are semi-automatic are available products in Australia. TePari and Automed products can be located relatively easily.

TePari provide hand held instruments that link to measuring scales that enable automatic dose relative to animal weight. Figure 6.16 illustrates the G20 and V20 products. Dosage is computed automatically, and the trigger switch requires low force, minimising potential for operator repetitive strain injury. The manufacturer estimates savings of $120 per animal when treating herds with Ivomec. The G20 and V20 TePari drench gun and injector retail from $1,650 each, and TePari weighing scales $2,500. Dealers in Australia can be found athttps://www.tepari.com.au/dealer-locator-au

a) b)

Figure 6.16 a) G20 Revolution Drench Gun, b) V20 Revolution Injection Gun (TePari Products Ltd, Oamaru, New Zealand)

The Automed system has a similar attributes. Again remotely powered it is able to vary dose according to animal weight and requires low trigger force. The WIFI ready instrument, figure 6.17, is easily converted between either oral or injection application using an insertable adapter. Retail price is stated as AU$ 1,420. Automed promotes additional advanced features for remote information feedback between a range of internet ready devices, ear tag readers, and also phones, management software running on farm computers.

Figure 6.17 Automed drench oral and injection gun with adjustable adaptor. (Automed PTY Ltd, Australia)

6.3.5 Blood sampling

Retrieving blood samples from cattle is within scope of current practice and can be used to provide absolute discrimination of disease and condition. A factor impeding regular approaches using blood samples is that current processing of samples is remote from the feedlot station. However recent advances in blood sample processing will enable future processing units on-site.

In the US it is noted that blood sampling is increasingly favoured by veterinarians for determining pregnancy (Mayo 2017). This potentially could save cost in equipment, time and the need for skilled operators if on site processing of blood samples was available.

White cell analysis systems based on opto- micro-fluidics technology have the potential to screen cattle for the presence of disease. This is relatively new in terms of products and build on earlier developments (Zhu et al 2011; Lecault et al 2012). The recent system QScout® of Advanced Diagnostics Inc, US could be adapted for application in feedlots. Both a low or high white blood cell count indicates that the immune system is under stress and could be used to indicate cattle to be segregated for further testing. This could reduce load and the cost of testing all cattle for multiple diseases.

6.3.6 DNA analysis techniques

Increasingly DNA can be used to discriminate more information about livestock. Both tissue samples and hair cell follicles are currently harvested for DNA Analysis. Further advances offer potential in feedlot induction applications (Wee et al 2015)

Tail-hair follicle sampling for DNA analysis requires induction staff to remove approximately 40 tail hairs (follicles intact) from the switch of the tail. This process is commonly achieved by wrapping the hair around a finger or pliers and pulling. Challenges with this sampling technique are avoiding contamination from dirt and manure and cross–contamination from other samples where samples are laid out to dry for processing before sending to the laboratory for analysis. Benefits of hair follicle DNA analysis are: Storage long-term at room temperature is possible and lower processing cost than other tissues.

Tissue Sampling: A Tissue Sampling Unit (TSU) is commonly applied such as the TSU of Allflex Australia Pty Ltd, Capalaba, Queensland, figure 6.18. This unit consists of a Sample Tube, Loading Apparatus, Cutter and TSU Applicator. The TSU applicator is first loaded with the Sample Tube and Cutter. The sample is collected by squeezing the TSU applicator across the ear of the animal. The small tissue sample is punched into the Sample Tube and is sealed in the one punch action. A benefit of this DNA sampling procedure is the low risk of contamination. Each Sample Tube has a unique identification consisting of a 2D barcode and number which can be purchased with a matching Animal Visual identification tag and NLIS tag.

Figure 6.18: Tube, Loading Apparatus and Cutter and TSU applicator (Allflex Australia Pty Ltd, 2015)

7. Concluding recommendations

The investigations at feedlot sites and the wider discussion with operators at further sites has shown that automation technology can be applied to improve the integrity and safety of the feedlot induction process. There will be greater consistency and accuracy with data and treatment application and response. It is unlikely that throughput can be increased over the manual operations, however it is more likely that at a feedlot station that is well automated, that the process will be continuous and not intermittent. There is even the prospect that the process could operate continuously, although this will depend on organisational possibilities and external arrangements concerning delivery and dispatch of cattle.

Financial justification for the addition of automation technology in feedlot induction can be modelled by contrasting the difference between a non-automated system and an automated system utilising smart tools assumed as commercially available products. Already 50% of tools are approaching a stage of being able to link and integrate with the wider system, sharing and communicating data automatically. These are termed 'Smart tools', e.g. ultrasound scanners, some drenching guns, injectors and scales. Taking account of financial savings of reduced labour, more efficient chemical application and reduced injury, and working from quotations and costs of equipment, the model demonstrates that the break-even point occurs well within a period of 3 years on the additional investment for automation (see Value Proposition in Appendix C).

To achieve greatest benefit from automation requires investment in infrastructure that will achieve two aims:

1. Calm animal behaviour through establishing guiding pens that encourage voluntary motion of cattle in a smooth operation. There are suitable designs of pens and gates to achieve this. There is evidence in the literature and internet to suggest this is likely to be achieved. The stage in the induction process where greatest inconsistent behaviour in cattle is found is on the approach to the Crush. As the Crush is a critical stage where assessment is achieved the focus needs to be at this point particularly. There is a solution in the form of conveyors that circumvent many of the issues, and a further solution is proposed in this report.

2. The means to automatically identify cattle at every stage needs to be put in place. In the future new technology, in the form of smart tools also embodying automation and robotic techniques technology, will be able to accurately record corresponding measurements and log the therapy applied. The 'Internet of Things' is the model that will reduce burden on operators in critical areas, such as the crush. In an automated system for this application no data should be input by operators if accuracy is to be maintained. With a system of this type in place it will be possible to improve the working environment of operators, their safety and the safety of the animals too. Further the investment will enable the process to grow with integrity, and adopt new technology opportunities when available in the future.

There is already some technology in the form of smart tools that can ease measurement and therapy processes. These assist operators to concentrate with less fatigue over long work periods of a shift. Automation in the form of smart tools can harness other technologies into a consistent process and reduce the number of measurement tasks while increasing the information obtained. The analysis of blood and DNA are such examples where new techniques and technology will in the near future offer potential for easier access to rapid results.

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Appendices

Appendix A

Papers prepared from results of Level 1 Review telephone survey (Paper 1), and from results of Level 2 Review site visits (Paper 2).

Paper 1. Quantifying costs of cattle feedlot inductions: Part A - Telephone survey of feedlots

Paper 2. Quantifying costs of cattle feedlot inductions: Part B - Time motion analysis of induction team tasks

Quantifying costs of cattle feedlot inductions: Part A - Telephone survey of feedlots

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Abstract
Cattle arriving at a feedlot are guided into a 'crush' where a team of staff perform an 'induction' consisting of tasks like ear tagging, vaccinations and drenching on each animal. Automation can potentially enhance the labour efficiency and safety of induction, however an understanding is firstly required of the range of induction processes and amount of automation in feedlots in Australia. A telephone survey was conducted of 16 large feedlots in Australia and identified that 1 in 4 feedlots had automation in 1-2 induction tasks outside of ear tag readers, weigh scales or pneumatic tools. Overall, 75% of participating feedlots suggested that automation to the cattle catch, drench, HGP, injections, dentition, breed detection or pregnancy testing would improve induction tasks. Priority automation opportunity areas were identified as more efficient and safer cattle catching, reduction of needlestick and kick injury to staff, and more precise dosage of drenches, HGP and injections to animals. Hence, it is concluded that there is opportunity for automation to enhance the labour efficiency and safety of induction in Australian feedlots.

Introduction
When cattle arrive at a feedlot they undergo a process termed ‘feedlot induction’ or ‘arrival processing’. Cattle are moved on-foot or by horse from holding pens, up a curved alleyway which enters a raceway to a processing ‘chute’ or ‘crush’. At the chute a number of processes may be applied which include (but are not limited to) scanning of National Livestock Identifications Scheme (NLIS) tag, application of a visual tag, weighing, determination of dentition, breed and sex, application of injectables and hormonal growth promotants, drenching, pregnancy testing, trimming of excess tail hair, horn tipping and corresponding data entry.

Feedlot induction is a labour intensive and very physical process for new cattle after arrival at a feedlot. There is opportunity for robotic and automation technologies to reduce the labour requirement of feedlot induction, with additional potential benefits of higher throughput, reduced animal stress and maximised workplace safety. However, an understanding is firstly required of how many staff, their tasks and costs associated with current feedlot induction processes in the Australian feedlot industry, and what automation and robotic technologies are available and feasible to use for feedlot induction.

Methodology
A survey instrument was developed and applied as a structured phone interview with relevant feedlot managers. A reference group of 16 large feedlots (greater than 10,000 head) were identified to participate in the phone interviews. The interviews were conducted in April to July 2017. Human Research Ethics approval was given for this survey. The survey instrument was used to obtain the number of feedlot induction staff, what they do, their pay rate, and amount of time per animal associated with feedlot induction processes, so as to calculate labour requirements, cost and efficiency. The survey questions are included in Appendix 1.

Numerical Questions
The survey was comprised of 27 items: 2 items categorised the breed and weight of cattle inducted; 8 items quantified time and labour resources used during induction; 6 items gathered information about induction facilities and equipment; and 4 items measured injuries to staff and cattle during induction.

Open Ended Questions

There were 7 open ended questions that pertained to induction tasks that could be improved, made faster, cheaper, safer or better quality, as well as questions about what parts of induction were already automated and the acclimation process prior to induction.

Results and discussion

Numerical Questions
Survey responses are presented in Tables 1 to 4. *Bos Taurus* was the most commonly inducted breed of cattle, followed by *Bos Indicus*<50% and *Bos Indicus*>50%. Each breed was inducted in at least 25% of the feedlots, and 75% of the feedlots inducted 2 or more breeds. The most common weight range of cattle at induction was greater than 400 kg, with the least common weight range being less than 300 kg.

The median labour scenario was a team of 4 staff inducting 370 cattle for 4 days per week, with inductions taking 5 hours per day. The median time per induction was calculated as 50 s, based on number of cattle processed and hours of processing per day (Table 2). Respondents of the survey indicated that a time of 30 s was considered most acceptable for cattle processing time. The median calculated labour cost for induction was $66,500 per year, and $18,000 per staff member. Hence, induction automation that allows 2 staff to be reallocated to another part of the feedlot would equate to an induction cost saving of $36,000 per year.

Most feedlots had one induction station without a spare station (Table 3). The most common crowd pen system was round tub with curved alley (56%), followed by custom or hybrid systems (32%). The position of weigh scales was most commonly under the crush, with none of the respondents having a pre-crush weigh box. The software used to record induction data spanned 3 commercial packages and in-house software, with the most common software being eLynx StockaID. Warwick Cattle Crush was the most common brand of crush and most feedlots had semi-automated sort gates. 1 in 4 feedlots had automation in 1-2 induction tasks outside of ear tag readers, weigh scales or pneumatic tools.

The median number of reported injuries in the past year was 8 for cattle, and 3 for staff (Table 4). 61% of common injuries to cattle were associated with entry or exit from the crush, and 24% with flooring (Figure 1). Nearly half of common injuries involved a potentially fatal condition (i.e. a bone fracture or lameness). All cattle injuries were associated with some aspect of the induction station infrastructure, e.g. the crush, flooring, laneway, pen, gates or fencing, versus injury caused by interaction with a tool, e.g. needlestick. In the Open Ended Questions ahead (Table 5), factors that were identified to improve the cattle catch in the crush were the flow of cattle, timing of the catch and the speed at which animals entered the crush.

The most common staff injuries (45%) were from tool-animal interaction at the crush involving needlestick, bang tailing, chin bar and ear tag removal (Figure 2). Animal-staff interaction resulting in kick injury in the laneway or bud box caused 35% of common staff injuries.

Table 1. Breed and weight of cattle inducted (*n* = 16 feedlots).

Q1. Number of cattle (×1000) inducted by breed, aggregated	*Bos Taurus*	*Bos Indicus<50%*	*Bos Indicus>50%*	*European*	*Wagyu*
	40%	28%	19%	7%	7%
Q1. Number of feedlots that induct this breed	*Bos Taurus*	*Bos Indicus<50%*	*Bos Indicus>50%*	*European*	*Wagyu*
	69%	69%	50%	44%	25%
Q1. Number of breeds inducted by feedlot	*One*		*Two*		*Three or more*
	25%		31%		44%
Q22. Number of feedlots that induct cattle in this weight range	*250-300 kg*	*300-350 kg*	*350-400 kg*	*400-450 kg*	*>450 kg*
	6%	63%	69%	81%	81%

Table 2. Time taken and labour costs for induction (*n* = 16 feedlots).

	Mean	Median	Min	Max	Mode
Q2. Days per week that inductions are performed	3	4	1	5	4
Q3. Number of inductions performed per year	50,000	48,000	7,000	130,000	18,000
Q10. Number of staff performing inductions per day	4	4	4	5	4
Q11. Number of cattle inducted per day on average	440	370	200	900	200
Q12. Hours of induction per day	5	5	3	10	4
Q13. Average pay rate of staff ($/hour)	22.13	22.00	18.91	27.00	22.00
Q14. Cost of contractors ($/head)	2.70	2.60	2.50	3.00	n/a
Q19. Acceptable time per induction (seconds)	40	30	30	90	30
Calculated: time per induction (seconds) (Q12 ÷ Q11)	50	50	30	80	60
Calculated: labour costs for induction per year ($) (Q10 × Q12 × Q13 × Q3 ÷ Q11)	62,000	66,500	11,000	135,000	n/a

Table 3. Induction facilities and equipment (*n* = 16 feedlots).

Q4. Number of induction stations	*One*			*Two*	
	75%			25%	
Q5. Brand/model of crush	*Warwick*	*Silencer*	*Thompson Longhorn*	*Other*	
	38%	19%	19%	25%	
Q6. Type of crowd pen system	*Round tub with curved alley*	*Bud box*	*Custom - bud box*	*Custom - curved alley*	*Custom - other*
	56%	13%	13%	6%	13%
Q7. Position of weigh scales	*Under crush*	*Above crush*	*Pre-crush weigh box*		
	69%	31%	0%		
Q8. Software used to record induction data	*eLynx StockaID*	*In-house*	*Possum Gully*	*Fusion*	
	63%	25%	6%	6%	
Q9. Automation in sort gates	*Semi-automated*	*Manual*	*Automated*		
	75%	19%	6%		
Open Ended Q2: Current automation in induction process	*Weight and RFID*	*Pneumatic crush, guns*	*Automatic backlining*	*Remote control crush*	*Prefilled data in software*
	100%	75%	13%	6%	6%
Open Ended Q7: Acclimation prior to induction	*Inducted straight off truck*			*Inducted straight off truck but with backgrounding*	
	69%			31%	

Table 4. Injuries to staff and cattle (*n* = 16 feedlots).

	Mean	Median	Min	Max	Mode
Q15. Number of cattle injuries in the last year during induction processes	7	8	0	12	10
Q17. Number of staff injuries in the last year during induction processes	2	3	0	5	1

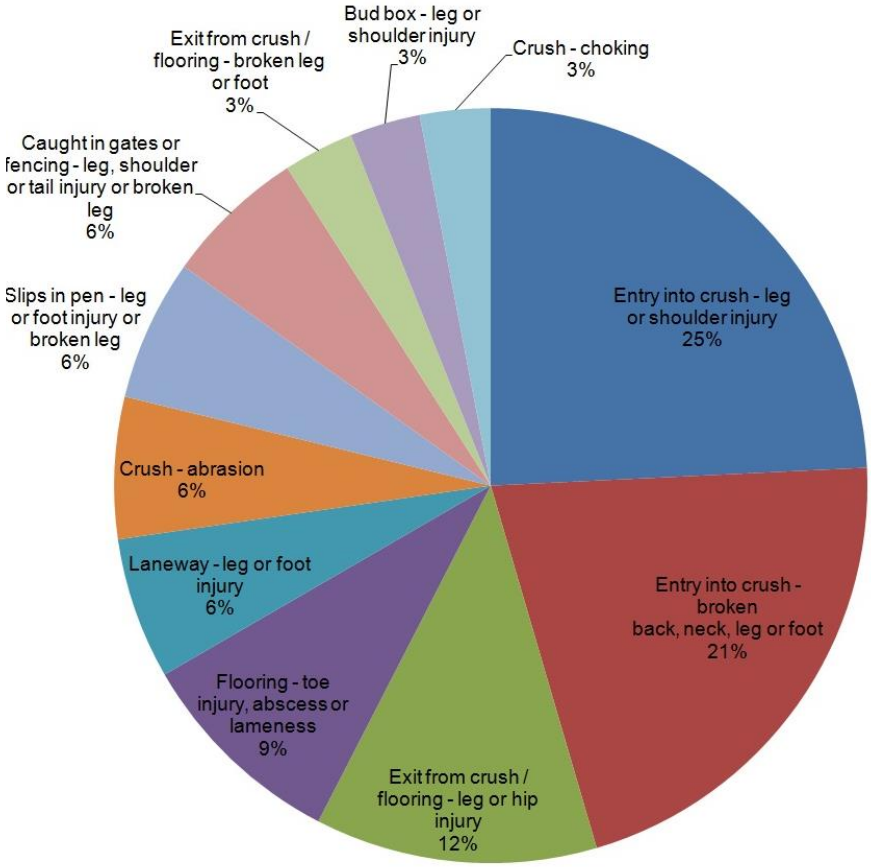

Figure 1. Q16. Common injuries to cattle during induction.

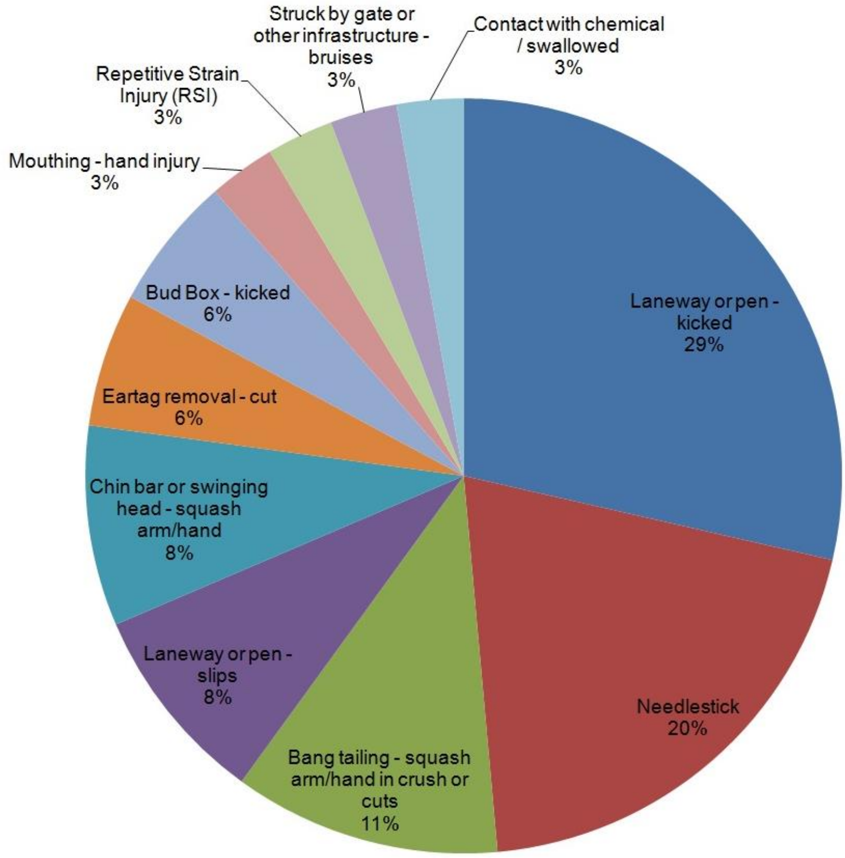

Figure 2. Q18. Common injuries to staff during induction.

Open Ended Questions

Responses from the Open Ended Questions about the induction tasks that could be improved, made faster, cheaper, safer or better quality were categorised by induction task, and then ordered from most- to least-mentioned induction task (Tables 5 to 9). Induction tasks listed under 'Other' were only mentioned once across the 16 responses. Table 5 indicates opportunities for automation as identified by feedlots in their responses; overall, 75% of participating feedlots suggested that automation to the cattle catch, drench, HGP, injections, dentition, breed detection or pregnancy testing would improve induction tasks.

The ordered list of induction tasks for each of the questions are displayed side-by-side in Table 10. The 'Overall score' for each task was calculated by summing the reciprocal of each row entry for that task, with equal weighting for each criteria.

Table 5. Open Ended Q1. Ordered list of induction tasks that could be improved.

Induction task	Summary of survey responses
1. Cattle catch	Reduce cattle injury through automation of catch with sensors; head restraint; no wear points; smooth flow of cattle; slow down cattle coming into the crush.
2. Drench, HGP and injections	Reduce labour and chemical usage; automatic back lining; reduce chemical exposure and needle handling; weight-based dosage; daily inventory stock take.
3. Bang tailing	Time consuming, costly and dangerous; knife injury.
4. Staff (all tasks)	More automation and less human interaction; ensure tasks are completed appropriately.
5. Loading race	Improved yard, shed and gate design; steady footing.
6. Ear tags	Better air driven ear tag guns; on-the-fly printing of ear tags; less preparation time and wastage of ear tags.
7. Dentition	Improve safety and reduce hand injury; make a non-contact test.
8. Other	Pregnancy testing; automatic weight data entry; DNA sampling.

Table 6. Open Ended Q3. Ordered list of induction tasks that could be made faster (bottle necks).

Induction task	Summary of survey responses
1. Cattle catch	Head movement, even with chin bar; timing of catch; hydraulic controls slower than manual controls.
2. Loading race	Loading cattle yard; cattle flow into race, depending on handling pre feedlot.
3. Staff	Scheduling trucks to arrive at the right time; scheduling staff resources relative to when cattle arrive; unloading cattle from trucks.
4. Ear tags	Making tags; preparing multiple different ear tags; replacing missing NLIS tags, required for 0.1% tags.
5. Data entry	Correcting mistakes in data entry in software; more data entry for more procedures; sorting or HGP amount determined by breed, weight, dentition
6. Other	Mouthing; bang tailing; DNA sampling; pregnancy testing; staff training; shed design.

Table 7. Open Ended Q4. Ordered list of induction tasks that could be made cheaper.

Induction task	Summary of survey responses
1. Drench, HGP and injections	Medications are expensive; wastage due to incorrect dosage, drench gun leakage and bottle breakage; potential savings from weight-based dosage.
2. Staff (all tasks)	Labour costs; training costs; potential savings from reduced number of staff.
3. Other	Time consuming tasks: replacing NLIS tags; cattle head control; DNA sampling; preparing ear tags; data entry.

Table 8. Open Ended Q5. Ordered list of induction tasks that could be made safer.

Induction task	Summary of survey responses
1. Loading race	Reduce staff contact with cattle; remove cattle pusher from the forcing yard.
2. Drench, HGP and injections	Cattle swinging their head; needle stick injury during vaccinations and HGP; potential savings from PPE, different application method or robotic control; back lining (chemical exposure).
3. Bang tailing	Accidental stabbing; reaching into crush.
4. Dentition	Hand injury from cattle swinging their head
5. Other	Pregnancy testing (crush injury).

Table 9. Open Ended Q6. Ordered list of induction tasks that could be made more efficient or better quality.

Induction task	Summary of survey responses
1. Drench, HGP and injections	More precise positioning on animal's body; animal-specific dosage; faster application; detect, monitor and audit HGP implants.
2. Ear tags	Combine or transfer ear tag information electronically to avoid wasting old tags; ear tag gun to hold different lot tags; more durable ear tag gun.
3. Data entry	Direct data entry; determination of breed, weight and dentition.
4. Dentition	Record dentition and keep with animal for pricing and auditing; assess dentition visually.
5. DNA sampling	Enhance sample collection (e.g. with respect to contamination); increase speed.
6. Other	Pregnancy testing - calf size and number of days pregnant; staff training - less time; shed design - less foot injury.

Table 10. Ordered list of induction task improvements - overall.

	Tasks that could be... (numbers indicate relative importance in ascending order for each column)					
Induction task	**Improved**	**Faster (bottle necks)**	**Cheaper**	**Safer**	**Better quality**	**Overall score**
Drench, HGP and injections	2		1	2	1	3.0
Cattle catch	1	1				2.0
Loading race	5	2		1		1.7
Staff (all tasks)	4	3	2			1.0
Ear tags	6	4			2	0.9
Bang tailing	3			3		0.7
Dentition	7			4	4	0.6
Data entry		5			3	0.5
DNA sample					5	0.3

Conclusions

There is opportunity for automation to enhance the labour efficiency and safety of induction in Australian feedlots, primarily via automated dosage of animals, calmer flow and immobilisation of cattle, and reduced contact between staff and animals. 1 in 4 feedlots had automation in 1-2 induction tasks outside of ear tag readers, weigh scales or pneumatic tools. There were no standardised crushes for feedlot induction, so automated technologies need to be robust to a range of cattle breeds and weight ranges. Induction labour costs indicate that induction automation which allows 2 staff to be reallocated to another part of the feedlot would equate to an induction cost saving of $36,000 per year.

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Appendix 1: Telephone survey questions

Q1. Please select one or more in relation to breed(s) of cattle that are inducted. What percent of each: *Bos Taurus* (British), *Bos Indicus* (e.g. Brahman) 0-50% content, *Bos Indicus* 50-100% content, European

Q2. How many days per week does your feedlot perform cattle inductions?

Q3. How many inductions does your feedlot perform per year?

Q4. How many induction stations (equipment, crush etc.) are at your feedlot site?

Q5. What brand/model of crush(es) do you operate?

Q6. What type of crowd pen systems do you have? Bud box, Round tub with Curved alley, Other?

Q7. Are your weigh scales under your crush, or do you have a pre-crush weigh box?

Q8. What software do you use to record induction data?

Q9. Do you have automated sort gates?

Q10. At your site(s) how many staff members perform your inductions on a daily basis? (i.e. including staff pushing cattle into tub or bud box)

Q11. How many cattle do you induct on a daily basis on average?

Q12. How many hours does it take on a daily basis on average?

Q13. When the feedlot staff induct, what is their average pay rate in $/hour?

Q14. If contractors are used, how do they charge - $/hour or $/head? List the costs.

Q15. How many injuries to cattle have you had over the last year during induction processes?

Q16. What is the most common injury to cattle in the induction process that is directly observable? Where do injuries occur in the process?

Q17. How many injuries to staff have you had over the last year during induction processes?

Q18. What is the most common injury to staff? Where do injuries occur in the process?

Q19. What is the acceptable time taken to induct a beast under general circumstances? (Starting from the crush operation of loading one beast until the crush operation of loading the next)

10 - 30 sec, 30sec - 1 min, 1 - 1.5 min, 1.5 - 2 min, 2 – 2.5 min, 2.5 – 3 min

Q20. What weight ranges are cattle entered into the feedlot at induction?

<200, 200-300, 300-400, 400-500, 500+

Open Questions for the managing staff overseeing the inductions:

Q1. What do you envisage would improve induction tasks?

Q2. What sections of your induction process are currently automated?

Q3. What is the biggest bottle neck in induction tasks?

Q4. If there are tasks that could be made cheaper during the induction process what are they and why are they expensive?

Q5. If there are tasks that could be made safer during the induction process what are they and why do they pose a safety risk?

Q6. If there are tasks that could be made more efficient/better quality during the induction process what are they and why are they inefficient/poor quality?

Q7. What is your acclimation process prior to induction?

Quantifying costs of cattle feedlot inductions: Part B - Time motion analysis of induction team tasks

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Abstract
Cattle that arrive at a feedlot are guided into a 'crush' where a team of staff perform tasks like ear tagging, vaccinations and drenches, in a process called feedlot 'induction'. Feedlot induction is a key process in lotfeeding which has potential for labour and time savings via automation. A time motion analysis of induction teams at 7 large feedlots was conducted to determine the labour costs of individual induction tasks and to identify priority tasks for automation. Ear tagging and cattle catch were the most time consuming tasks for all 7 feedlots. On average, the equivalent of 1 labour unit was waiting across the induction team for the time the animal was in the crush, and the cattle catch was 24% of the time to induct one animal. The results suggest that up to 2 labour units could be reallocated to other parts of the feedlot via automation of induction processes.

Introduction
After cattle arrive at a feedlot, cattle are guided through a raceway to a 'crush' where the cattle undergo an 'induction' consisting of procedures for traceability, performance, and health and welfare. Typical induction tasks are weighing, vaccinations, application of feedlot ear tags, bang tailing and dentition checks to determine age. Feedlot induction is a labour intensive and very physical process, and for large feedlots, is performed by a co-ordinated team of 3-6 staff situated about the crush.

There is opportunity for robotic and automation technologies to reduce the labour requirement of feedlot induction, with additional potential benefits of higher throughput, reduced animal stress and maximised workplace safety. However, an understanding is firstly required of the number of staff, staff tasks and costs associated with current feedlot induction processes in the Australian feedlot industry.

Methodology
A time motion analysis was conducted of staff tasks during cattle inductions at 7 large feedlots in Queensland and New South Wales. The 7 observation sites ranged in size from 10,000 to 55,000 head, and from 17,000 to 90,000 cattle inductions per year. Each observation site was monitored for at least 200 head per day (2-3 hours) for 5 days throughout July and August 2017. Human Research Ethics approval was given for the observation of staff tasks. Each induction staff member gave their consent for the observation by signing of a consent form.

Video monitoring apparatus for the time motion analysis consisted of 5 camera units (one shown in Figure 1) that were mounted at areas of interest around the induction crush (Figure 2). For reference, a schematic layout of induction staff around the crush is provided in Figure 3. Each camera unit consisted of a sports action camera (GoPro Hero 4) and 10 Ah power bank on a plywood mounting board. Video capture on all the cameras was triggered simultaneously using the camera WiFi remote control. The set of 5 camera units was installed at the start of the observation session and removed from the site each day after 200 head had been inducted, during a short break by induction staff. Removal of the cameras from the site each day was necessary so that video data from the cameras could be downloaded.

Recorded video was downloaded from each of the 5 camera units and was compiled into a single video file in MP4 format using video editing software (Nero Video 2016). The single video file enabled the 5 camera viewpoints to be reviewed simultaneously. Time motion analysis was performed on the compiled video using the package BORIS (Behavioral Observation Research Interactive Software). BORIS enables a user to define keyboard shortcuts for different actions (e.g. crush closes, crush opens, oral drench), then record the timestamp for different actions by pressing of keyboard shortcuts during video playback.

Results and discussion

Time motion analysis - enumeration of induction tasks and analysis protocol

A protocol for performing the time motion analysis of staff induction tasks from the compiled video was developed (Appendix 1). Development of the protocol enabled definition of induction efficiency metrics (Table 1) and identification of the component actions for each induction task (Table 2; also Appendix 2).

Figure 1. Detail view of a single wireless camera unit.

Figure 2. Camera units on posts or portable bollards at an induction facility.

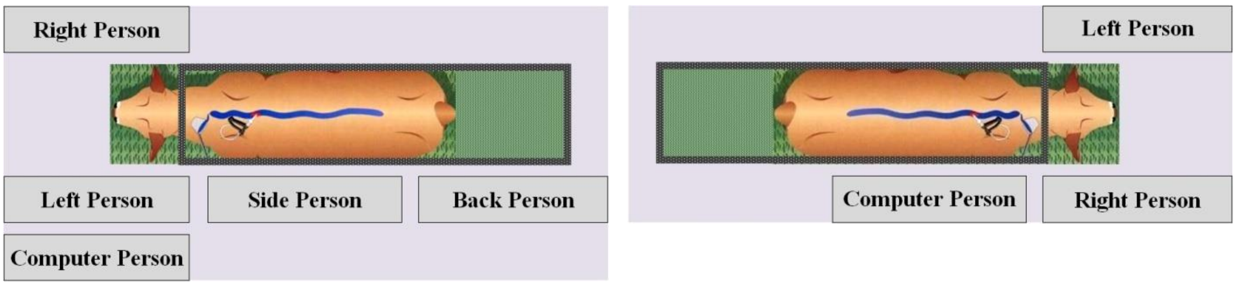

Figure 3. Layout of induction staff about the crush for 2 of the observation sites, here with 5 staff and 3 staff.

Table 1. Calculation of induction efficiency metrics (also refer Appendix 1).

Metric	Calculation of metric
Time for induction of one animal (s)	Time between when one animal is immobilised in the crush ('Crush - caught') and the next animal is immobilised in the crush ('Crush - caught').
Time with crush empty (%)	Time between when one animal has left the crush ('Crush - empty') and the next animal is immobilised in the crush ('Crush - caught').
Time with crush full (%)	Time between when an animal is immobilised in the crush ('Crush - caught') and the animal is released from the crush restraints after the induction tasks are completed ('Crush - release').
Time with staff holding tool (%)	Time between when staff lift a tool from the crush / tool hanger / workbench ('Hands - full') and staff replace the tool after completing a task ('Hands - empty').
Time with staff reaching for tool (%)	Time between when staff move towards a tool and staff commence lifting tool ('Hands - full'). Typically, occurs directly after 'Hands - empty' from preceding induction task.
Time with staff waiting (%)	Time when animal is in the crush (Crush full), that staff are neither holding a tool nor reaching for a tool, as other staff are completing other induction tasks.
Labour units waiting	'Staff waiting' percentage multiplied by total number of staff.

Table 2. Description of typical induction tasks and component actions across the 7 feedlots.

Induction task	Job actions* to complete the induction task (and number of staff performing job actions)
Cattle catch	*Immobilise animal in crush so that induction tasks can be performed (1-2 staff)* • **Cattle catch** - Pull levers at workbench or remote control to release animal and catch next animal • **Apply head scoop** - Reach for button and push button on crush; or pull lever at workbench
Ear tagging (left and / or right ears)	*Apply visual numbered tags to animal's ear/s for visual identification of animals (1-2 staff)* • **Remove ear tag** - Turn; lift tool from workbench; reach for ear and pull tool against ear tag; retract tool; return tool to workbench • **Empty remover tool** - Dispense ear tag remnant from tag remover at workbench • **Scan ear tag barcode** - Lift new ear tag and barcode scanner on workbench; scan ear tag; return barcode scanner to workbench • **Load ear tag gun** - Place new ear tag on gun on workbench • **Check for ear tag** - Reach for ear and inspect if ear tag is present • **Read ear tag number** - Inspect ear tag on animal and annunciate number • **Apply ear tag** - Reach for ear and position gun and trigger gun; retract gun
Data entry	*Record data on computer about each animal (1-2 staff)* • **Data entry** - Enter data into computer on workbench • **Identify breed** - Turn; inspect animal in crush and record breed
Dentition	*Determine age of animal by inspecting number and type of teeth (1-2 staff)* • **Mouthing** - Reach for mouth and bend and inspect mouth; annunciate result • **Dentition notch ear tag** - Turn; lift tool from workbench; reach for ear and position gun and apply notch; retract tool; return tool to workbench
HGP	*Inject Hormonal Growth Promotant implant into animal's ear (2 staff)* • **HGP injection** - Lift gun from workbench; reach for ear and position gun and trigger gun; retract gun; return gun to workbench • **HGP notch ear** - Lift tool from workbench; reach for ear and position tool and apply notch; retract tool; return tool to workbench • **HGP clean gun** - Dip gun in chemical wash tray on workbench
Bang tailing	*Cut long hairs of animal's tail (1 staff)* • **Bang tailing** - Lift tool from workbench; reach for tail and position tail on tool and cut tail hair; retract tool; return tool to workbench and dispense tail hair • **Check length of tail** - Reach for tail and inspect length
Pregnancy	*Perform pregnancy test of animal (1 staff)*

testing	• **Pregnancy testing** - Reach for animal and insert probe; turn; inspect screen and annunciate result; retract probe; return probe to wash bucket • **Clean probe** - Lift probe from wash bucket; dip probe in wash bucket; turn
Oral drench	*Vaccine applied to mouth of animal (1 staff)* • **Oral drench** - Lift gun from tool hanger; reach for mouth and pull trigger; retract gun; return gun to tool hanger
Backline	*Parasiticide applied to back of animal (1 staff)* • **Manual backline** - Lift gun from tool hanger; reach for back and pull trigger; retract gun; return gun to tool hanger • **Automatic backline** - Reach for button and push button on crush
Neck injections	*Vaccine / parasiticde applied to neck of animal (1 staff)* • **One neck injection** - Lift gun from tool hanger; reach for neck and pull trigger; retract gun; return gun to tool hanger • **Two neck injections** - Lift 2 guns from tool hanger, reach for neck with each gun and pull triggers; retract both guns; return guns to tool hanger
Nasal drench	*Vaccine applied to nose of animal (1 staff)* • **Nasal drench** - turn; lift gun from tool hanger; reach for nose and position gun and trigger gun; retract gun; return gun to tool hanger
Ear injection	*Vaccine applied to ear of animal (1 staff)* • **Ear injection** - lift gun from workbench; reach for ear and position gun and trigger gun; retract gun; return gun to workbench

* A single induction task typically has multiple component job actions performed by multiple staff.

Time motion analysis - induction efficiency metrics

Induction efficiency metrics calculated from the time motion analysis of each of the observation sites are reported in Table 3. The time motion analysis identified that:

- induction time per animal ranged from 16.9 to 33.8 seconds
- one job action (i.e. reach for tool, lift and apply to animal, replace tool) was on average 6.5 s
- the time to catch the animal in the crush was typically 24% of the time to induct one animal
- reaching for a tool was typically 16% of the time required for each task
- team members were typically waiting for 22% of the time the animal was in the crush, which equated to an average of 1 labour unit across the induction team

Table 3. Induction efficiency metrics.

Feedlot number	Total number of induction: Staff	Tasks	Job actions	Job actions per staff	Average time (s): Induct one animal	One job action	Average % time spent with: Staff holding tool	Staff reaching for tool	Staff waiting	Crush empty	Labour units waiting
1	5	11	20	4	30.2	6.1	50	14	21	15	1
2	3	6	9	3	16.9	8.7	43	30	0	27	0
3	3	7	9	3	33.8	7.0	28	9	35	28	1
4	3	9	10	3	19.7	6.3	50	15	12	23	0
5	3	6	11	4	18.9	6.6	33	18	21	28	1
6	4	7	14	4	17.9	4.6	25	12	39	24	2
7	3	8	14	5	21.5	5.9	37	13	26	24	1
Average	**3**	**7**	**12**	**4**	**23.0 s**	**6.5 s**	**38%**	**16%**	**22%**	**24%**	**1**

Time motion analysis - time requirements itemised by induction task

The total time for each induction task consisted of summing the staff reach time, as well as staff hold tool time, for all the job actions across the induction team related to the induction task (e.g. HGP injection, HGP notch and HGP clean gun for the HGP induction task in Table 2). The resulting time requirements for various induction tasks are presented in Table 4, and Figures 4 and 5 (next page).

The induction tasks that were performed at all 7 sites were ear tagging, cattle catch, data entry and mouthing. Ear tagging (20 s), cattle catch (13.8 s), HGP (10.6 s) and pregnancy testing (20 s) were top 5 most time consuming tasks for all feedlots that performed that task. Job actions that involved close proximity of staff to the ears and mouth of the animal (e.g. ear tags and mouthing) took 20% more time than job actions involving tools that enabled staff to be further from the animal (e.g. nasal or oral drench), or involving injections to the neck of the animal.

Ear tagging and HGP were the most complex tasks (i.e. involving the most component job actions). The least most commonly performed tasks were pregnancy testing and a vaccine / parasiticide injection to the base of the ear (ear injection). Vaccines and / or parasiticides were most commonly applied as a backline, followed by nasal drench, neck injections, oral drench and ear injection.

Table 4. Time for common job actions requiring staff proximity to animal in crush*

Induction task	Average time (s) per task
Ear tags, ear tag removal, HGP and ear notch	5.3
Mouthing	5.6
Sprays/injections to head	4.1
Sprays/injections to body	3.8

*For comparison, the catch takes on average 13.3 s.

Amount of automation in induction tasks

At the 7 feedlots, there were 6 instances of automation across an aggregated number of 54 induction tasks. Hence, 89% of instances of induction tasks had no automated features. In summary:

- Feedlots with at least one instance of automation (besides weight, RFID) = 38%
- Induction tasks with at least one instance of automated features = 42%
- Instances of induction tasks without automated features = 89%
- Instances of induction tasks without automated features, and not automated at any of the participating feedlots = 64%

Key contributors to delays in processing were restlessness in cattle and crush effectiveness. Potential causes of restlessness in cattle were that animals would become confused because the gates would be opening and shutting while they were approaching or entering the crush. Some of the races leading to the crush allowed too many animals in the queue prior to entering the crush causing them to climb over each other. Animals were observed to be less stressed when the animal spent less than 6 minutes in the induction shed, and 15-30 seconds in the crush.

Some crush models did not provide adequate restraint of the animal during induction. Animals would be caught in the crush with either their heads, or heads and necks, becoming jammed under the crush gates. Delays in processing were observed to be caused by the head scoop not being used so the animal's head was moving, or the crush and race being empty while animals were waiting at the start of the race.

Conclusions

Ear tagging and cattle catch were the most time consuming tasks for all 7 feedlots. On average, the equivalent of 1 labour unit was waiting across the induction team for the time the animal was in the crush, and the cattle catch was 24% of the time to induct one animal. The results suggest that up to 2 labour units could be reallocated to other parts of the feedlot via automation of induction processes. Across the observed feedlots, there were 89% instances of induction tasks that did not have automated features.

Acknowledgements
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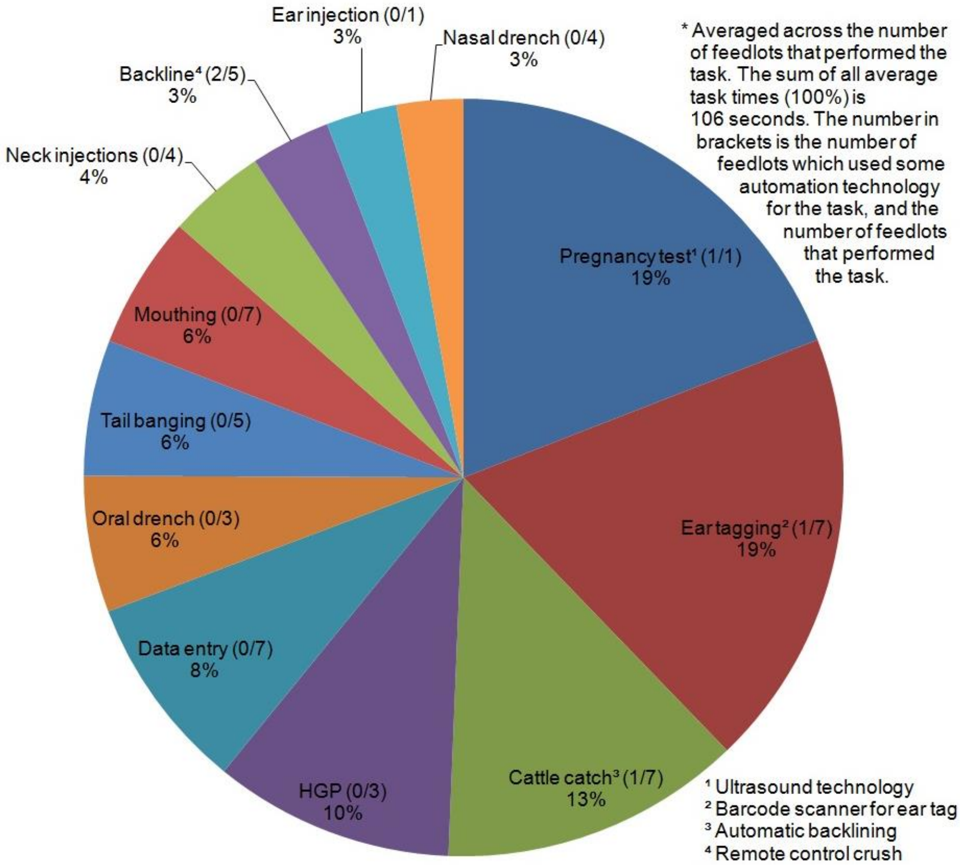


Figure 4. Time spent on individual induction tasks, averaged across 7 feedlots*.

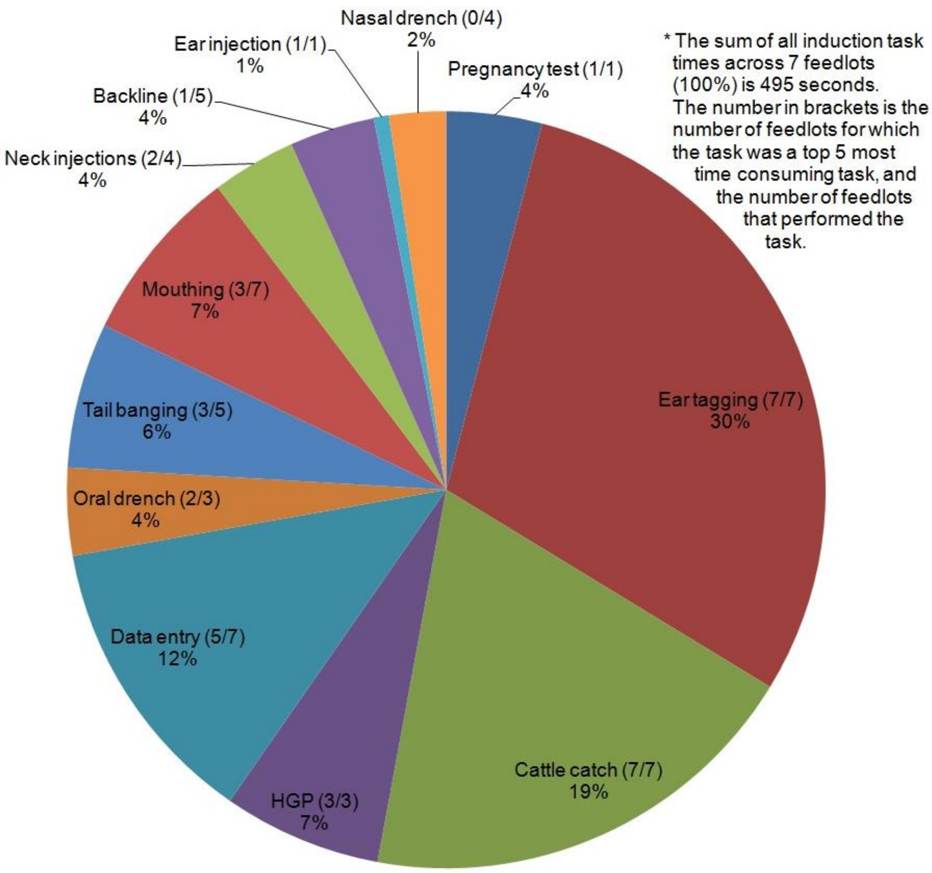


Figure 5. Time spent on individual induction tasks, summed across 7 feedlots*.

Appendix 1: Time motion analysis - protocol

Save as separate BORIS observations.

- Viewing #1 {First, Middle, Last} 20 animals: Playback at 2x speed.
  Record with keyboard shortcut:

CSH CGT	Crush - caught (Key 'J')
CSH REL	Crush - release (Key 'K')
CSH EMP	Crush - empty (Key 'L')

- Viewing #2 - repeat for {Left, Right, Side, Back, Computer} Person
  Record with keyboard shortcut:

HND FUL	Hands - full (Key '1')
HND EMP	Hands - empty (Key '2')

- Viewing #3 - repeat for each HND FUL event of {Left, Right, Side, Back, Computer} Person
  Record using coding pad (total of 39 job actions):

CMP DTY	Computer - data entry
CMP DFT	Computer - drafting
CMP IDB	Computer - identify breed
CSH CTL	Crush - controls
CSH SCP	Crush - head scoop
DEN MTH	Dentition - mouthing
DEN NTC	Dentition - notch ear tag
DRN NAS	Drench - nasal
DRN ORL	Drench - oral
DRN BKL	Drench - backline
DRN BKA	Drench - backline auto
HGP INJ	HGP - injection
HGP NTC	HGP - notch ear
HGP CLN	HGP - clean gun

INJ EAR	Injection - behind ear
INJ NCK	Injection - neck
INJ NC2	Injection - neck x 2
PRG TST	Pregnancy - test
PRG CLN	Pregnancy - clean probe
TAI TRM	Tail - trim hair
TAI CHK	Tail - check length
TGL REM	Ear tag left - remove
TGL LOD	Ear tag left - load gun
TGL TAG	Ear tag left - tag
TGL EMP	Ear tag left - empty tool
TGR CHK	Ear tag right - check
TGR REM	Ear tag right - remove
TGR LOD	Ear tag right - load gun
TGR TAG	Ear tag right - tag
TGR RDN	Ear tag right - read number

TGL BC2	Ear tag left 2 - scan barcode
TGL LO2	Ear tag left 2 - load gun
TGL TA2	Ear tag left 2 - tag
TGL EM2	Ear tag left 2 - empty gun

Not typical:

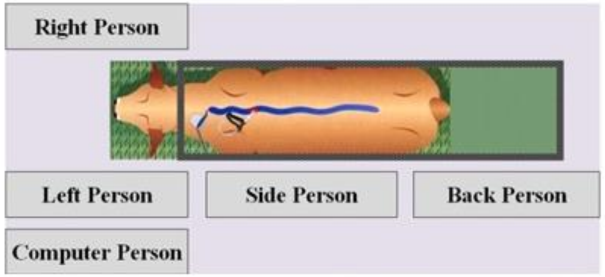
HRN TRM	Horn - trim
HRN TRM	Horn - check length
JOB ERR	Job error
TGL CLN	Ear tag left - clean ear
TGR RFD	RFID tag

  Also record: For each site, what each job involves, e.g. turn; reach; lift; push

- Export aggregate observations as csv file and sort records by time stamp

Appendix 2: Time motion analysis - data from 7 feedlots

Feedlot #1



Right Person		Wait time 0 s; and total time for jobs:	Reach for tool 7.6 s	Tool in hand 28.0 s
1	Ear tag left - remove (TGL REM)	Turn; lift tool from **workbench** Reach for ear and pull tool against ear tag Retract tool Return tool to **workbench**	2.8 s	3.9 s
2	Dentition - mouthing (DEN MTH)	Reach for mouth and tactile check	1.0 s	6.0 s
3	Ear tag right - tag (TGR TAG)	Reach for ear and position gun and trigger gun Retract gun	1.2 s	4.9 s
4	HGP - notch ear (HGP NTC)	Lift tool from **workbench** Reach for ear and position tool and apply notch Retract tool Return tool to **workbench**	0.4 s	5.9 s
5	Drench - oral (DRN ORL)	Lift gun from **tool hanger** Reach for mouth and pull trigger Retract gun Return gun to **tool hanger**	1.0 s	3.1 s
6	Ear tag right - load gun (TGR LOD)	Place new ear tag on gun on **workbench**	1.2 s	4. 2 s

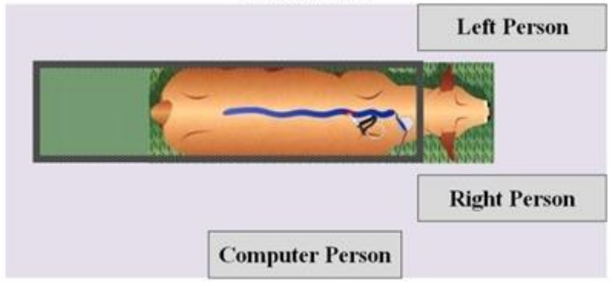
Left Person		Wait time 1.0 s; and total time for jobs:	Reach for tool 5.6 s	Tool in hand 21.1 s
1	Ear tag left - tag (TGL TAG)	Lift gun from **workbench** Reach for ear and position gun and trigger gun Retract gun Return gun to **workbench**	0.5 s	5.9 s
2	Crush - head scoop (CSH SCP)	Reach for button and push button on **crush**	0.9 s	1.2 s
3	HGP - injection (HGP INJ)	Lift gun from **workbench** Reach for ear and position gun and trigger gun Retract gun Return gun to **workbench**	0.6 s	7.2 s
4	Drench - nasal (DRN NAS)	Turn; lift gun from **tool hanger** Reach for nose and position gun and trigger gun Retract gun Return gun to **tool hanger**	1.1 s	2.7 s
5	Crush - head scoop (CSH SCP)	Reach for button and push button on **crush**	0.9 s	1.2 s
6	Ear tag left - load gun (TGL LOD)	Place new ear tag on gun on **workbench**	1.0 s	2.2 s
7	HGP - clean gun (HGP CLN)	Dip gun in chemical wash tray on **workbench**	0.6 s	0.7 s

Computer Person		Wait time 7.3 s; and total time for jobs:	Reach for tool 1.1 s	Tool in hand 19.3 s
1	Crush - controls (CSH CTL)	Pull levers at **workbench** to release animal and catch next animal	0.5 s	10.1 s
2	Computer - data entry (CMP DTY)	Enter data into computer on **workbench**	0.6 s	9.2 s

	Side Person	Wait time 23.4 s*; and total time for jobs: *Wait time includes 4.6 s pushing cattle	Reach for tool 0.9 s	Tool in hand 3.4 s
1	Injection - neck (INJ NCK)	Lift gun from **tool hanger** Reach for neck and pull trigger Retract gun Return gun to **tool hanger**	0.5 s	1.5 s
2	Drench - backline (DRN BKL)	Lift gun from **tool hanger** Reach for back and pull trigger Retract gun Return gun to **tool hanger**	0.4 s	1.9 s

	Back Person	Wait time 2.2 s; and total time for jobs:	Reach for tool 6.0 s	Tool in hand 19.5 s
1	Pregnancy - test (PRG TST)	(Already holding probe) Reach for animal and insert probe Turn; inspect screen and annunciate result Retract probe Return probe to **wash bucket**	3.5 s	11.1 s
2	Tail - trim hair (TAI TRM)	Lift tool from **workbench** Reach for tail and position tail on tool and cut tail hair Retract tool Return tool to **workbench** and dispense tail hair	0.5 s	4.8 s
3	Pregnancy - clean probe (PRG CLN)	Lift probe from **wash bucket** Dip probe in **wash bucket**; turn	2.0 s	3.6 s

Feedlot #2

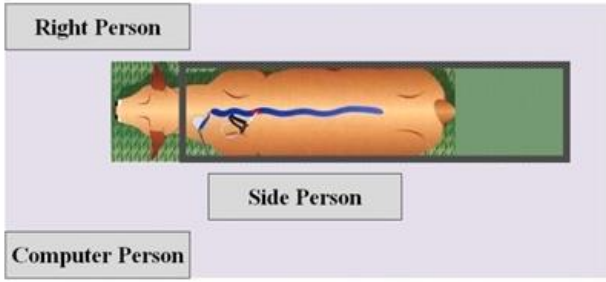


	Left Person	Wait time 0 s; and total time for jobs:	Reach for tool 4.6 s	Tool in hand 16.5 s
1	Ear tag left - load gun (TGL LOD)	Place new ear tag on gun on **workbench**	2.6 s	5.0 s
2	Ear tag left - scan barcode (TGL BCD)	Lift new ear tag and barcode scanner on **workbench** Scan ear tag Return barcode scanner to **workbench**	0.5 s	1.7 s
3	Drench - backline auto (DRN BKA)	Reach for button and push button on **crush**	1.1 s	2.4 s
4	Ear tag left - tag (TGL TAG)	(Already holding ear tag gun) Reach for ear and position gun and trigger gun Retract gun	0.3 s	3.3 s
5	Drench - nasal (DRN NAS)	Turn; lift gun from **tool hanger** Reach for nose and position gun and trigger gun Retract gun Return gun to **tool hanger**	0.1 s	4.1 s

Right Person		Wait time 0 s; and total time for jobs:	Reach for tool 7.3 s	Tool in hand 13.4 s
1	Crush - controls (CSH CTL)	Pull levers next to **crush** to release animal and catch next animal	3.9 s	12.8 s
2	Dentition - mouthing (DEN MTH)	Reach for mouth and bend and inspect mouth	3.4 s	3.0 s

Computer Person		Wait time 0 s; and total time for jobs:	Reach for tool 7.3 s	Tool in hand 15.8 s
1	Computer - data entry (CMP DTY)	Enter data into computer on **workbench**	2.7 s	7.8 s
2	Computer - identify breed (CMP IDB)	Turn; inspect animal in **crush** and record	4.5 s	5.6 s

Feedlot #3

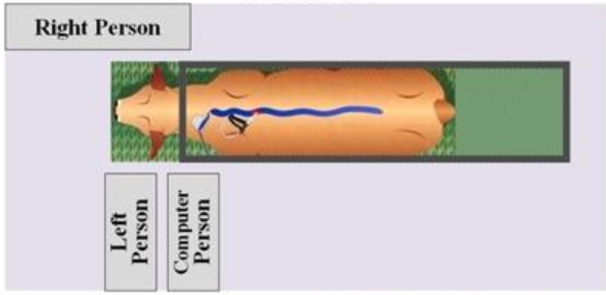


Right Person		Wait time 13.5 s; and total time for jobs:	Reach for tool 4.3 s	Tool in hand 17.4 s
1	Ear tag right - read number (TGR RDN)	Inspect ear tag and annunciate number to Computer Person	1.0 s	1.0 s
2	Dentition - mouthing (DEN MTH)	Reach for mouth and bend and inspect mouth	1.8 s	7.0 s
3	Ear tag right - load gun (TGR LOD)	Place new ear tag on gun on **workbench**	1.0 s	5.6 s
4	Ear tag right - tag (TGR TAG)	Reach for ear and position gun and trigger gun Retract gun	0.5 s	3.8 s

Side Person		Wait time 23.3 s*; and total time for jobs: *Wait time includes 12.8s pushing cattle	Reach for tool 4.0 s	Tool in hand 8.7 s
1	Drench - backline auto (DRN BKA)	Reach for lever and pull lever on **crush**	1.0 s	2.6 s
2	Injection - neck x 2 (INJ NC2)	Lift gun 1 and gun2 from **tool hanger** Reach for neck with gun 1 and pull trigger 1 Retract gun 1 Reach for neck with gun 2 and pull trigger 2 Retract gun 2 Return gun1 and gun 2 to **tool hanger**	1.8 s	3.9 s
3	Tail - check length (TAI CHK)	Reach for tail and inspect length	1.2 s	2.2 s

Computer Person		Wait time 13.2 s; and total time for jobs:	Reach for tool 1.0 s	Tool in hand 21.8 s
1	Crush - controls (CSH CTL)	Pull levers at **workbench** to release animal and catch next animal	0.5 s	12.3 s
2	Computer - data entry (CMP DTY)	Inspect data on computer on **workbench**	0.5 s	9.5 s

Feedlot #4

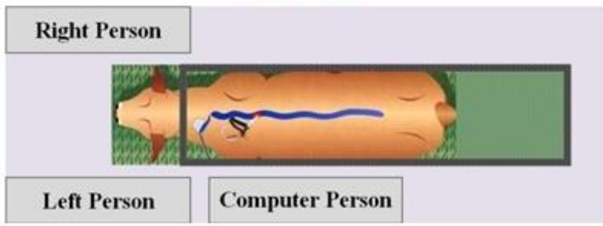


	Right Person	Wait time 1.4 s; and total time for jobs:	Reach for tool 2.2 s	Tool in hand 20.0 s
1	Dentition - mouthing (DEN MTH)	Reach for mouth and bend and inspect mouth	0.7 s	3.8 s
2	Ear tag right - tag (TGR TAG)	(Already holding ear tag gun) Reach for ear and position gun and trigger gun Retract gun	0.5 s	3.6 s
3	Drench - oral (DRN ORL)	Lift gun from **tool hanger** Reach for mouth and pull trigger Retract gun Return gun to **tool hanger**	0.3 s	6.1 s
4	Ear tag right - load gun (TGR LOD)	Place new ear tag on gun on **workbench**	0.7 s	6.4 s

	Left Person	Wait time 0.3 s; and total time for jobs:	Reach for tool 4.7 s	Tool in hand 18.6 s
1	Crush - controls (CSH CTL)	Reach for remote control on **workbench** and press buttons to release animal and catch next animal	3.9 s	9.7 s
2	HGP - injection (HGP INJ)	Lift gun from **workbench** Reach for ear and position gun and trigger gun Retract gun Return gun to **workbench**	0.5 s	6.0 s
3	Injection - ear (INJ EAR)	Lift gun from **tool hanger** Reach for behind ear and pull trigger Retract gun Return gun to **tool hanger**	0.3 s	2.9 s

	Computer Person	Wait time 6.9 s; and total time for jobs:	Reach for tool 3.5 s	Tool in hand 13.2 s
1	Drench - backline (DRN BKL)	Lift gun from **tool hanger** Reach for back and pull trigger Retract gun Return gun to **tool hanger**	1.0 s	4.0 s
2	Tail - trim hair (TAI TRM)	Lift tool from **workbench** Reach for tail and position tail on tool and cut tail hair Retract tool Return tool to **workbench** and dispense tail hair	0.5 s	6.2 s
3	Computer - data entry (CMP DTY)	Enter data into touchscreen computer on **workbench**	2.0 s	3.0 s

Feedlot #5

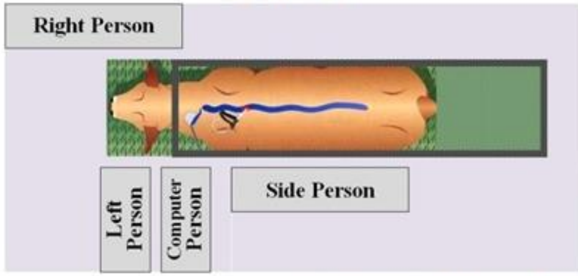


	Right Person	Wait time 10.5 s; and total time for jobs:	Reach for tool 5.4 s	Tool in hand 13.5 s
1	Dentition - mouthing (DEN MTH)	Reach for mouth and bend and inspect mouth	3.5 s	1.8 s
2	Ear tag right - tag (TGR TAG)	(Already holding ear tag gun) Reach for ear and position gun and trigger gun Retract gun	0.8 s	6.4 s
3	Ear tag right - load gun (TGR LOD)	Turn; place new ear tag on gun on **workbench**	1.1 s	5.3 s

	Left Person	Wait time 5.2 s; and total time for jobs:	Reach for tool 6.5 s	Tool in hand 19.3 s
1	Ear tag left - remove (TGL REM)	Lift tool from **workbench** Reach for ear and pull tool against ear tag Retract tool Return tool to **workbench**	4.3 s	4.4 s
2	Ear tag left - tag (TGL TAG)	Lift gun from **workbench** Reach for ear and position gun and trigger gun Retract gun Return gun to **workbench**	0.8 s	8.7 s
3	Ear tag left - load gun (TGL LOD)	Place new ear tag on gun on **workbench**	1.0 s	4.4 s
4	Ear tag left - empty tool (TGL EMP)	Dispense ear tag remnant from tag remover tool at **workbench**	0.4 s	1.8 s

	Computer Person	Wait time 3.2 s; and total time for jobs:	Reach for tool 4.3 s	Tool in hand 23.4 s
1	Crush - controls (CSH CTL)	Pull levers to release animal and catch next animal	1.2 s	12.5 s
2	Injection - neck x 2 (INJ NC2)	Lift gun 1 from **tool hanger** Reach for neck and pull trigger 1 Retract gun 1 Lift gun 2 from **tool hanger** Reach for neck and pull trigger 2 Retract gun 2 Return gun 1 and gun 2 to **tool hanger**	1.8 s	3.2 s
3	Drench - oral (DRN ORL)	Lift gun from **tool hanger** Reach for mouth and pull trigger Retract gun Return gun to **tool hanger**	1.3 s	6.7 s
4	Computer - data entry (CMP DTY)	Inspect data on computer on **workbench**	0 s	1.0 s

Feedlot #6



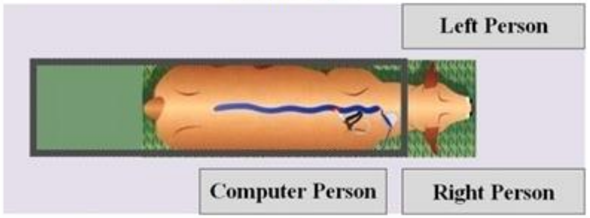
	Right Person	Wait time 23.2 s; and total time for jobs:	Reach for tool 1.6 s	Tool in hand 3.6 s
1	Dentition - mouthing (DEN MTH)	Reach for mouth and bend and inspect mouth	1.1 s	2.4 s
2	Drench - nasal (DRN NAS)	(Already holding drenching gun) Position gun and trigger gun Retract gun	0 s	0.7 s
3	Ear tag right - check (TGR CHK)	Reach for ear and inspect	0.5 s	0.5 s

	Left Person	Wait time 0 s; and total time for jobs:	Reach for tool 2.6 s	Tool in hand 25.6 s
1	Crush - controls (CSH CTL)	Pull levers at **workbench** to release animal and catch next animal	1.0 s	13.7 s
2	Ear tag left - remove (TGL REM)	Lift tool from **workbench** Reach for ear and pull tool against ear tag Retract tool Return tool to **workbench**	0.4 s	2.0 s
3	Ear tag left - tag (TGL TAG)	Lift gun from **workbench** Reach for ear and position gun and trigger gun Retract gun Return gun to **workbench**	0.3 s	3.6 s
4	Ear tag left 2 - tag (TGL TA2)	Lift gun from **workbench** Reach for ear and position gun and trigger gun Retract gun Return gun to **workbench**	0.4 s	4.4 s
5	Ear tag left 2 - empty gun (TGL EM2)	Dispense tag remnant from tool at **workbench**	0.5 s	1.9 s

	Computer Person	Wait time 2.2 s; and total time for jobs:	Reach for tool 6.1 s	Tool in hand 19.3 s
1	Ear tag left - load gun (TGL LOD)	Place new ear tag on gun on **workbench**	1.3 s	3.2 s
2	Ear tag left 2 - scan barcode (TGL BC2)	Lift new ear tag and barcode scanner on **workbench** Scan ear tag Return barcode scanner to **workbench**	1.5 s	4.9 s
3	Ear tag left 2 - load gun (TGL LO2)	Lift new ear tag and gun from **workbench** Turn; check computer screen and place new ear tag on gun Return gun to **workbench**	1.4 s	4.5 s
4	Computer - data entry (CMP DTY)	Turn; enter data into computer on **workbench**	1.9 s	6.7 s

	Side Person	Wait time 18.5 s; and total time for jobs:	Reach for tool 2.8 s	Tool in hand 6.3 s
1	Drench - backline (DRN BKL)	Lift gun from **tool hanger** Reach for back and pull trigger Retract gun Return gun to **tool hanger**	1.1 s	2.5 s
2	Tail - trim hair (TAI TRM)	Reach for tail and position tail on tool and cut tail hair Dispense tail hair	1.7 s	3.8 s

Feedlot #7



	Left Person	Wait time 14.4 s; and total time for jobs:	Reach for tool 3.0 s	Tool in hand 12.8 s
1	Injection - ear (INJ EAR)	Lift gun from **tool hanger** Reach for behind ear and pull trigger Retract gun Return gun to **tool hanger**	1.0 s	4.1 s
2	Ear tag left - remove (TGL REM)	Turn; lift tool from **workbench** Reach for ear and pull tool against ear tag Retract tool Return tool to **workbench**	1.0 s	2.6 s

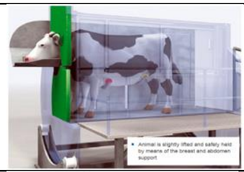
			Reach for tool	Tool in hand
3	HGP - injection (HGP INJ)	Lift gun from **workbench** Reach for ear and position gun and trigger gun Retract gun Return gun to **workbench**	1.0 s	5.1 s
4	HGP - clean gun (HGP CLN)	Dip gun in chemical wash tray on **workbench**	0 s	1.0 s
	Right Person	**Wait time 5.6 s; and total time for jobs:**	**Reach for tool 4.8 s**	**Tool in hand 22.8 s**
1	Ear tag right - remove (TGR REM)	Lift tool from **workbench** Reach for ear and pull tool against ear tag Retract tool Return tool to **workbench**	0.5 s	5.6 s
2	Ear tag left - tag (TGL TAG)	Lift gun from **workbench** Reach for ear and position gun and trigger gun Retract gun Return gun to **workbench**	0.8 s	2.8 s
3	HGP - notch ear (HGP NTC)	Lift tool from **workbench** Reach for ear and position tool and apply notch Retract tool Return tool to **workbench**	0.5 s	4.0 s
4	Dentition - mouthing (DEN MTH)	Reach for mouth and bend and inspect mouth	0.8 s	2.6 s
5	Drench - nasal (DRN NAS)	Turn; lift gun from **tool hanger** Reach for nose and position gun and trigger gun Retract gun Return gun to **tool hanger**	0.7 s	2.6 s
6	Dentition - notch ear tag (DEN NTC)	Turn; lift tool from **workbench** Reach for ear and position gun and apply notch Retract tool Return tool to **workbench**	0.5 s	2.6 s

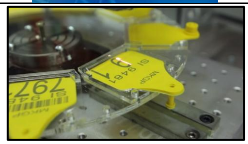
			Reach for tool	Tool in hand
7	Ear tag right - load gun (TGR LOD)	Place new ear tag on gun on **workbench**	1.0 s	2.6 s
	Computer Person	**Wait time 4.3 s; and total time for jobs:**	**Reach for tool 4.7 s**	**Tool in hand 23.1 s**
1	Crush - controls (CSH CTL)	Pull levers next to **crush** to release animal and catch next animal	1.1 s	9.8 s
2	Tail - trim hair (TAI TRM)	Turn; lift tool from **workbench** Reach for tail and position tail on tool and cut tail hair Retract tool Return tool to **workbench** and dispense tail hair	1.6 s	8.2 s
3	Computer - data entry (CMP DTY)	Enter data into computer on **workbench**	2.0 s	5.1 s

Appendix B

List of Technology

The following table summarises information on technology identified in Section 6.

Item/ Section Number	Image	Model	Typical Supplier	**Typical Cost** AU$ unless otherwise indicated	**Availability** Available / Needs Development / Adaptation / Future
Guides and Pens					
Turret Gate 6.1.1		9ft gate + curved panels power drive + remote control	Catagra Group PO Box 3456 Caloundra, QLD 4551	$34,205	Available
Banss Crush 6.1.2		Crush restraint supports animals	BANSS AG, Germany www.banss.de	Price on application	Needs adaption
Clipex 2000 Crush 6.1.2		Crush catches & restrains animals	CLIPEX fencing & Stockyards, 624 PROGRESS RD, WACOL QLD, 4076	$19,990	Available
Circular Race Pen 6.1.2		Concept: Primarily for Equine use	-	-	Development
Actuated Drafting Gates 6.1.2		Hydraulic gates 2 way, 3 way, 5 way	Catagra Group PO Box 3456 Caloundra, QLD 4551	Price on application	Available

Item/ Section Number	**Image**	**Model**	**Typical Supplier**	**Typical Cost** AU$ unless otherwise indicated	**Availability** Available / Needs Development / Adaptation / Future
Managing animal identification and correlation with data					
Database and Management Software 6.2.1		StockaID	ELynx PTY Ltd 68-70 West St, Toowoomba QLD 4350	Price on Application Function dependent	Available/ Development for Application
Printable Ear Tag 6.2.1		Farmers Mail Box	http://www.fmb.com.au	From $1.35 each	Available
Bar code Printer 6.2.1		SH-G350C/D	Liaocheng Shenhui, CHINA	From $1,500	Available
Bar code laser engraver 6.2.1		M20abc for example	Engraving Supplies Ltd, 14 Florence St. West Perth 6005	From $10,000	Available
Assessments and Therapies					
Power tail trimmer 6.3.1		Tailwell2	Shoof International Ltd, New Zealand	$450	Available

Item/ Section Number	**Image**	**Model**	**Typical Supplier**	**Typical Cost** AU$ unless otherwise indicated	**Availability** Available / Needs Development / Adaptation / Future
Ultrasound for Pregnancy testing 1 6.3.2		WED 3000 VET	Keebomed Phone:630 888 2888 Email: Keebomed@live.com	$4,000	Available
Ultrasound for Pregnancy testing 2 6.3.2		Reproscan, Repro Rectal Probe	Reproscan P.O.Box3471, Erina, NSW, 2250 Sales@AustralianMedicalSystems.com	Price on Application	Available
3D Quik Hand Sprayer 6.3.3		http://www.3dcattle.comgreatplainsmarketing@gmail.com	3-D Cattle Equipment, LLC., 320 Old Waters Hwy, Pine Ridge, Ar 71961, USA,	Price on application	Available
The Cow Sprayer 6.3.3		www.cowsprayer.com sales@cowsprayer.com	US Suppliers	US$2,999 + Shipping	Available
Kattleguard Fly Control 6.3.3		dairysupplyonline.com issuu.com/geafarmtechnologies gmbh/docs/2013_gea_supplies_catalog _usa/264	Kattleguard, Dairy Solutions, Inc. 6382 Hosfield Drive, Tulare, CA 93274, USA.	Price on application	Available

Item/ Section Number	Image	Model	Typical Supplier	Typical Cost AU$ unless otherwise indicated	Availability Available / Needs Development / Adaptation / Future
Drench Gun 6.3.3		TePari G20	Catagra Group PO Box 3456 Caloundra, QLD 4551	$1,650	Available
AutoMed 6.3.4		Email: info@automed.io	Automed PTY Ltd, PO Box 491, Belconnen, ACT, Australia . Phone +61 2 6100 3016	From $1420	Available
Drench Injector 6.3.4		TePari V20	Catagra Group PO Box 3456 Caloundra, QLD 4551	$1,650	Available
Weighing scales 6.3.4		TePari Bars or Scales	Catagra Group PO Box 3456 Caloundra, QLD 4551	$2,500	Available
Tissue Sampler Loading Apparatus 6.3.5		Tissue Sampler and Cutter	Allflex Australia PTY	Price on Application	Available
Tissue Sampler Applicator 6.3.5		Applicator	Allflex Australia PTY	Price on Application	Available

Appendix C

Value of automation in a feedlot induction environment

Automation can establish benefit for each feedlot business and for the Australian industry as a whole in front of international competition.

Automation technology applied in different industrial sectors has increased productivity, accuracy, consistent quality, and the integrity of production processes and products. The automotive industry is often cited as the prime example. The benefits support improved working conditions, greater intensity in production and strengthen market position of a business or industry. Intensity of production does not necessarily imply faster production. For Feedlot induction the benefit will stem from more persistent and robust production, even 24/7 in addition to a reduction in operating cost. Unlike the manufacture of artefacts, dealing with animals is less consistent in terms of operating conditions and this is the challenge for automation technology. Using the technology to enhance the capability of people in the working environment has the advantage of realising benefit and managing the complexity within an acceptable cost. This is often referred to as a semi-automatic process.

The product in feedlot induction is one of adding value to cattle for quality meat. The processes of measurement applied to animals is complex, and results from variable animal size, shape and behaviour. For the business, reputation and consistent qualities are important. Market share relies on ‘Good reputation’ that stems from a reliable supply of high quality products. Built trust strengthens market participation and share. The investment of automation enables maintenance of lead position working from the state of the art.

For staff, automation technology can reduce or enhance operator manual skill requirements. The displacement of staff from hazardous working conditions into improved, safer and flexible roles is important. Jobs previously considered physically arduous will transform into roles suited to both genders. Greater flexibility in the workforce and in employment is valuable, particularly in a large country of sparsely distributed population centres.

Value Proposition
To illustrate financial justification alone for the addition of automation technology in feedlot induction, one can adopt a model that contrasts the difference between a non-automated system and an automated system utilising smart tools assumed as commercially available products (Table 1). Already 50% of tools are approaching a stage of being able to link and integrate with the wider system, sharing and communicating data automatically. These are termed 'Smart tools’, e.g. ultrasound scanners, some drenching guns, injectors and scales.

Taking account of the financial savings of Table 2, and working from quotations and costs of equipment the model demonstrates that the break-even point occurs well within a period of 3 years on the additional investment made in Table 1.

Assumptions for the model are stated at the end of Table 1.

Table 1 Comparison on expenditure and saving between Conventional and Smart Systems.

YEAR 1	**Conventional**	**Smart**	**Contrast**
Cost of full yard of pens and guides (Not including delivery and installation cost)	$265,000	$385,000	+$120,000
Database and software	$12,000 per 1000 head pa	$20,000 per 1000 head pa	+$ 80,000
10 tools for therapy/ diagnosis	$15,000	$25,000	+$ 10,000
		Contrasting Expenditure	**$138,000**
		Annual saving (Table2)	-$ 108,320
		Year 1 Total: Total Spent	**$ 38,000**
		Cumulative TOTAL SAVING	**$ 38,000 (Loss)**

YEAR 2	**Conventional**	**Smart**	**Contrast**
Depreciation on Full Yard and pens (12 months)	$26,500	$38,500	+$ 12,000
Database and software	$12,000 per 1000 head pa	$20,000 per 1000 head pa	+$ 8,000
10 tools for therapy/ diagnosis	$1,500	$ 2,500	+$ 1,000
		Contrasting Expenditure	**$ 21,000**
		Annual saving (Table 2)	-$108,320
		Year 2 Total: Total Gain	**$ 87,320**
		Cumulative TOTAL SAVING	**$ 49,320 (Gain)**

YEAR 3	**Conventional**	**Smart**	**Contrast**
Depreciation on Full Yard and pens (12 months)	$26,500	$38,500	+$ 12,000
Database and software	$12,000 per 1000 head pa	$20,000 per 1000 head pa	+$ 8,000
10 tools for therapy/ diagnosis	$1,500	$ 2,500	+$ 1,000
		Contrasting Expenditure	**$ 21,000**
		Annual saving (Table 2)	-$108,320
		Year 3 Total: Total Gain	**$ 87,320**
		Cumulative TOTAL SAVING	**$ 136,640 (Gain)**

Assumptions used in Table 1

1. **Non-automated System:** The installation of a facility as currently with manually activated tools and database software with manual input of sensory data, manual or remotely activated gates and Turret gate as the solution for a Crowd Pen.
2. **Integrated automated / Semi automated solution:** The installation of a facility as currently with autonomous/ semi-autonomous tools, database software integrating the automatic retrieval of sensory data, control of the guiding pens and gates, and feedback of the status of operation to operators. Machine vision would be a key element to control gates and interaction with cattle, including the Turret gate. Some of this technology is available or approaching available. The automated Turret gate for this application is feasible with some development. 10 commercial smart tools have been assumed. 6 have been identified already in the Technical report as available. Others are in development, and an additional $10,000 has been allowed to purchase the expected smart as opposed to manual commercial variants.
3. **Software is purchased on a license for database and other functions.** In the application of animal management it is often based on the size of herd. 1000 head has been assumed for the benefit of the calculation.

4. **Notes describing the source of values** used in the calculation are listed under 'Definition of Terms and Cost Groups used in the model' as follows.

Table 2 Direct savings.

Potential cost saving	Annual value	Justification
Labour costs		
Half-size induction team (remove labour 2 people)	$ 36,000	Labour cost based on telephone survey
Induction team takes half the time	$ 18,000	Labour cost based on telephone survey
Inventory costs	$ 25,000	Assuming 5% saving from weight-based dosage, on $500k total medication costs
Staff injury costs		
Workers compensation	$ 20,000	As provided by large feedlot
Throughput reduction	$ 4,320	Labour to overcome 6% reduction in throughput (6% - indicated by feedlot)
Injuries to animals	$ 5,000	Assuming loss of 5 animals per year
Total	**$ 108,320**	

Definition of Terms and Cost Groups used in the model

The model does not account for indirect savings, e.g.: reduction in loss of weight gain to animals (e.g. animals reach target weight in 1 less day), due to less stressful induction; more consistency in induction processes; availability and diversity of feedlot employment opportunities, due to less physical induction processes.

The Cost of a typical full Feedlot Induction Yard is $265,000. This includes forcing yard, Turret gate, race, crush, gates, drafting gate and drafting pens. This statement is from Catagra Group. The cost of delivery and installation is additional and is dependent on location.

The Cost of a Smart Full Feedlot Induction Yard is estimated at $385,000 on the same basis as the 'Typical full induction yard' above, with additions. 5 smart gates automatically operated and the turret gate automatically operated using machine vision to control the interaction with cattle. Some development is yet required, and is feasible. A software license for the machine vision and regular ear tag readers within the system will be the baseline for the integrated automated system. The allowance for the additional cost takes into account the cost of ear tag readers $300, writers $1500, machine vision software, cameras ($300 ea) and automated gates. Actuated gates by IR controls are already within the cost of the Typical induction yard above.

Depreciation of equipment in business is normally considered over a 10 year period. This cost has been assumed in the model applied to the initial investment.

The cost of software for a database is known as stated as a license t $6,000 pa per 500 head of cattle. A smart system will require additional functions to automatically manage the system and automatically record data. Such software is known to be under development, similar attributes are available to the dairy industry where smart gates are demonstrated that detect animal proximity. Machine vision will be needed to partition groups of animals with minimal disturbance in smart gates and Turret systems. This is feasible and needs development.

Smart tools are becoming available that can integrate as 'The internet of things'. Already one can count on ultrasound equipment for pregnancy check $5,000, drench guns $1,650, injectors $1,650 and weighing scales $2,500 as commercially available. Other smart instruments will be available to collect DNA samples in a controlled method. The contrasting prices between commercially available conventional and smart tools is approximately $800- $1,000. In the model an average additional value of $1,000 per tool has been assumed for 10 tools.