Final report

Evaluation of automated bunk management – feedlot cattle performance

Project code: B.FLT.1012

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Executive summary

Cattle performance in a feedlot setting is driven primarily by their feed intake. The amount of feed allocated to a pen of cattle is managed to optimise productivity and health while reducing feed waste. Feed intake is managed by bunk callers and requires accurate estimation of the quantity of feed remaining in a bunk following a 24-hour feeding period and consideration of several environmental, cattle, and management factors to determine feed allocation for the next 24-hour period.

Bunk calling is a complex process. The caller has to consider the diet and its fermentability, the historical feed intake, pen size, health status, and environmental conditions while modulating rumen pH and driving production. This is a considerable amount of information to evaluate quickly, and poor decisions can result in acidosis, feed wastage, a loss of potential gains from lower than optimum feed intake, and reduced profitability to the feedlot. Poor decisions can be compounded during times of staff turnover, when training new staff and even during shift changes.

The development and commercialisation of a lidar-based bunk scanner by Meat & Livestock Australia (MLA) and Manabotix Pty. Ltd. which can accurately determine the amount of feed remaining in a bunk, has enabled the expansion of a framework to automate bunk management. This world-first achievement enables semi-automation of bunk management utilising scanning data to assist the human decision-making process.

In order to fully automate bunk management, an algorithm was developed by Manabotix Pty. Ltd. in conjunction with MLA and Bovine Dynamics Pty. Ltd. that incorporated cattle characteristics, feed remaining information from the bunk scanner for the preceding 24 h, previous feed intake history, weather, daily head count changes and handling information to determine the daily feed allocation for a pen of cattle for clean-bunk management.

The objectives of this project were to determine the effects of bunk scanning for feed quantity estimation and use an algorithm for feed allocation decision-making on the performance (average daily gain, carcass weight, feed intake) and health of cattle.

This research is targeted directly at supporting feedlots and their staff by aiming to develop a framework that can be implemented to improve their general bunk management practices, support staff and management to make well-informed decisions, and potentially in the future, return a performance benefit for the cattle. Additionally, the project explored fully automating the process of feed allocation with no human input, except for initial algorithm development.

To determine the feasibility of automating bunk management, a randomised block design study was conducted in a commercial feedlot to compare the effects of semi-automation and full automation on cattle performance, health and carcass outcomes.

This project was conducted by comparing the following three treatments:

Traditional Human Bunk Management: Human staff members visually estimated the quantity of feed in the bunk following a 24-hour feeding period and available historical pen feed intake, (i.e., bunksheet) data and used that estimate to determine the amount of feed a pen was allocated that day.

Automated Bunk Scanning and Human Feed Allocation (Semi automation): The automated bunk scanner determined the quantity of feed in the bunk following a 24-hour feeding period. Human callers used that information and available historical pen feed intake, (i.e., bunksheet) data to determine the amount of feed a pen allocated that day.

Automated Bunk Scanning and Algorithm Feed Allocation (Full automation): The automated bunk scanner determined the quantity of feed in the bunk following a 24-hour feeding period and an algorithm determined the amount of feed allocated that day.

Bos indicus cross steers (n=5509) with an average entry weight of 420.2 Kg were inducted into a commercial feedlot and randomly assigned to one of three treatments (traditional (control), semi-automation, full automation) across 7 blocks with 21 pens total (n= 7; 254 to 265 hd per pen). Cattle were fed for an average of 109 days, during which time their daily feed deliveries (As Fed), morbidity, mortality, re-implant weight and pen exit weights were recorded. Treatments were slaughtered at equivalent days of feed endpoint, remained separate during lairage and were slaughtered at the same abattoir. Aus-meat hot standard carcass weight, dressing percentage, eye muscle area, rib fat, P8 fat, hump height, chiller assessment pH, Aus-Meat meat colour and ossification were recorded for all carcasses.

Performance results showed no difference (P>0.05) between the semi or full-automation treatments for the key performance outcomes of Final Body Weight, Average Daily Gain, Dry Matter Intake, Feed:Gain across the overall feeding period. Moreover, automation of feed calling (semi and full) did not negatively impact (P>0.05) any animal health parameters, mortality, or economically relevant carcass values. Dry matter intake (P=0.031) was greater for the control and semi-automated treatments between d 0 and reimplant. However, from reimplant to exit, dry matter intake (P=0.001 was greater for the control and fully-automated treatments. These differences in feed intake did not impact overall weight gain and feed intake.

This study suggests that bunk management can be automated to reach equivalent performance outcomes, with no negative impacts on health and relevant carcass outcomes, as a highly-skilled bunk caller.

The result of this study can redefine how we approach bunk management in the future. It provides the industry with a framework to partly or fully automate their bunk management program depending on their needs. The result would allow them to achieve the outcomes of a highly-skilled bunk caller year-round, easing staffing pressure and providing critical data for management and nutritionists. Future study on a refined algorithm is recommended with the aim of providing an economic benefit to producers, along with testing the automated system on other breeds of cattle and in different climatic conditions.

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1. Background

The feed intake of individuals is regulated by a combination of physical and metabolic mechanisms and influenced by dietary and environmental components (Fitzsimons et al., 2017, National Academies of Sciences, Engineering and Medicine, 2016). This complex process makes managing the intake of a group of cattle far more complicated than managing their feed requirements individually, and numerous factors can significantly impact any one individual, including feed composition, palatability, presentation, breed, sex, age, weather, health, population density (National Academies of Sciences, Engineering and Medicine, 2016).

Over the past 40 years, the feedlot industry's animal management unit has grown steadily, with producers managing larger pens of cattle and larger cattle numbers overall (Greenwood, 2021). This growth has allowed for greater profitability; however, specific issues have arisen when larger groups of cattle are managed as a single unit, particularly relating to health and nutrition. Moving away from individual animal management has made it more challenging to handle the requirements of an individual, and as a result, producers are forced to work toward a group average. For this reason, managing the nutritional requirements of large groups of animals is a highly complex process due to the differences in nutritional requirements, feeding behaviour and health status between individuals in the same group (Elam, 1971, Preston and Willis, 2013).

Feedlot cattle also perform at their best in terms of feed intake and digestive health status when they have consistent intakes of feed energy which is achieved in part by avoiding fluctuations in the amount of feed offered (Anderson and O'Connor, 1990, Cooper et al., 1998, Schwartzkopf-Genswein et al., 2004).

The practice developed to overcome the issues of feeding cattle in large groups at high daily feed intake levels while mitigating digestive disturbances is called bunk management. Broadly, bunk management is the process of allocating and delivering the correct amount of feed to a pen of cattle each day to maximise feed intake and feed efficiency while minimising digestive disorders and waste (Pritchard and Bruns, 2003, Schwartzkopf-Genswein et al., 2003). Predictions of the feed required by a pen of cattle per day is based on the amount of feed delivered the previous day and the resulting consumption for the previous 24-hour period (Dyck et al., 2007). This information is combined with several other factors, including the historical feed intake, the feeding period, health status and weather conditions to determine the daily feed allocation.

The cornerstones of bunk management include consistent and reliable information on feed intake and consistent and well-informed decision making on feed allocations.

Conventionally, the evaluation of feed in the bunk each day has been conducted visually by a human bunk caller. These visual and subjective observations are made daily at scheduled intervals and are used to determine the feed remaining in the bunk prior to the day's feed delivery and the pen's rate of consumption (Halachmi et al., 2015, Pritchard and Bruns, 2003). Correctly determining feed intake history is critical for production as poor bunk calling can lead to incorrect allocations, fluctuations in feed intake, feed wastage and digestive disturbances (Dorea and Cheong, 2019, Pritchard, 1993).

There is significant room for human error in the traditional procedure of bunk management. Bunk calling is a difficult task as it requires a high level of skill and experience, it is fatiguing, and the caller must analyse past intake data quickly, along with considerations on the age, breed, body condition, ration fermentability, weather and many more variable before making a decision. While good decisions will improve profits across the yard, poor bunk calling can result in poor performance and feed efficiency, increased waste, and digestive disorders (Galyean and Eng, 1998, Nagaraja and Lechtenberg, 2007, Pritchard and Bruns, 2003). This issue can also be compounded when more than one individual with differing experience or strategies is bunk calling for the same pens of cattle.

Across the feedlot industry, the concept of bunk management has evolved substantially since the early 1950s, yet a consensus on bunk management philosophy does not exist in commercial feedlots or the literature. There are still several areas that require research, and as in all fields of agriculture, there is room for expansion of knowledge and improvement in production processes (Pritchard, 1998).

Automation of bunk management is the next step in improving this process for producers and livestock. This process uses an automated bunk scanner (Australian Patent Number: AU2018203945B1; US Patent Number: US11118956B2) that reads and calculates the quantity of feed remaining and, therefore, the feed consumption of the pen more accurately than human bunk callers (McCarthy et al. 2018ab). The information is then integrated into an algorithm developed to remove human error from the decision-making process by determining the feed allocation.

This project aims to deliver health, welfare, environmental and economic benefits to cattle and producers by increasing the accuracy of feed intake information acquired and the consistency of the feed allocation process. These areas of improvement may include a greater and more consistent feed intake over the feeding period with reductions in digestive disorders commonly associated with feed intake fluctuation. Thus, it could reduce the incidence of gains lost through under allocation of feed and reduce the amount of wasted feed and production lost through digestive disturbances when feed is over-allocated. Through these improvements in efficiency, health and welfare, the project has the potential to reduce the overall environmental impact of feedlot cattle while increasing the overall production of beef produced per animal.

Integrating these critical biological and physical processes associated with nutrition and bunk management with modern remote sensing and decision-making tools allows for precise, accurate and well informed on-farm decisions that benefit producers and livestock.

2. Objectives

This project will determine the effect of semi and full automation of bunk management on feedlot cattle health and performance at one feedlot site.

The objectives of this project are:

- To develop a framework that can allow for the automation of bunk management in a commercial setting
- To determine the feasibility of automating bunk management on the performance (average daily gain, carcass weight, feed intake) and cattle health (morbidity, mortality, bulling).
- To determine the value proposition of automating bunk management.

3. Methodology

3.1 Animal welfare

Approval to conduct the trial was given by the Queensland Department of Agriculture and Fisheries, Animal Ethics Committee (reference number CA 2019/08/1311). Animals were housed and used in accordance with the animal welfare principles established and maintained by Bovine Dynamics Pty Ltd.

3.2 Experimental design

A randomised block design evaluated three bunk management treatments on cattle efficiency (DMI, F:G), body weight gain (ADG, Final weight gain), health (morbidity, mortality, bulling%) and carcass outcomes (Aus-meat hot standard carcass weight, dressing percentage, P8 fat, MSA rib fat depth, MSA marbling score, hump height and ossification).

The three treatments were:

- Conventional Bunk Management (control): Human bunk callers visually estimated the quantity of feed in the bunk following a 24-hour feeding period and used that estimate and available historical pen feed intake information, (i.e., bunksheet data) to determine the amount of feed a pen was allocated that day.
- Automated Bunk Scanning and Human Feed Allocation (Semi automation): The automated bunk scanner determined the quantity of feed in the bunk following a 24-hour feeding period. Human bunk callers used that information and available historical pen feed intake information, (i.e., bunksheet data) to determine the amount of feed a pen was allocated that day.
- Automated Bunk Scanning and Algorithm Feed Allocation (Full automation): The automated bunk scanner determined the quantity of feed in the bunk following a 24-hour feeding period and an algorithm determined the amount of feed a pen was allocated that day.

Figure 1 Automated bunk scanner developed by Manabotix Pty. Ltd and Meat & Livestock Australia Limited.

3.3 Algorithm commissioning

Prior to trial, the bunk scanner and algorithms including the bunk management software platform developed by Manabotix Pty Ltd. were commissioned so that each component was operating correctly at the host site. During commissioning, the bunks for each of the enrolled trial pens were swept and geo-referenced with the baseline bunk conformation mapped, i.e., The start and end positions of each pens bunk were located in global coordinates based on GNSS measurements to allow the scanner to identify each pen, along with having a baseline scan of each bunk to know the volume of the empty bunk. This was critical so that when a bunk full of feed was scanned, the feed volume could be by subtracting the lidar point-cloud data from the baseline of the bunk.

The fully automated algorithm was tested for 45 days on 5 pens of starter cattle (265 hd per pen) in a pilot study. Feed allocation, feed remaining, sweeping events and incidence of digestive disorders were monitored on a daily basis, and iterative refinements were made over the course of the pilot study to improve the accuracy and precision of the algorithm. For more information on the design and commissioning of the bunk scanner technology, please refer to the previous reports B.FLT.1009, B.FLT.0166, B.FLT.7009 and B.FLT.1006 by MLA.

3.4 General

The study was undertaken at a 70,000 head capacity commercial feedlot in Southeast Queensland between March and August 2021. Scales were professionally calibrated prior to the commencement and by staff during the trial for Feed truck scales (weekly), weighbridge scales (biannually) and induction scales (daily).

Twenty-one (21) pens of Bos indicus cross steers (n=5509; 254-265 steers per pen) were used in the study with an average induction weight of 420.17 kg, dentition 0-4 teeth and tropical breed content (TBC) 30 to 100%.

On arrival at the feedlot (d – 1), cattle were kept separate from other vendors and were provided equal access to hay and water. At induction (d 0), the cattle were individually weighed on a chute (Thompson Longhorn), with +/- 1 kg breaks, and animals outside the weight range of 360-480 kg BW were excluded. Animals were identified with a unique visual ID and RFID tag. They were then administered with the recommended veterinary health treatments for the host site, with all animals receiving the same veterinary treatments including a hormonal growth promotant (HGP) implant containing 20 mg estradiol-17β and 200 mg trenbolone acetate (Component TE200; Elanco Australia, Sydney), a *Megasphera elsdensii* oral drench (Lactipro; MS Biotec, USA), a live bovine herpes virus vaccine (Rhinogard; Zoetis Australia, Sydney), a topical parasiticide (Virbamec Low Volume Pour-on,"Virbamec" Abamectin 5mg/mL topical single active; Virbac Australia, Sydney). The cattle were then allocated into 1 of 3 treatments (1 animal to control, 1 animal to semi automation, 1 animal to full automation; then repeated) as they passed through the processing chute. Once a unique block was filled, they started their feeding period. A total of seven blocks were inducted between March 1 and April 4, 2021.

Each cattle block were housed in contiguous pens of identical size and design (66 m × 56 m). Treatments groups were randomly assigned to pens within a block. Pens within a block were at a similar pen cleaning status. The pens had equal cloth shade area (450m^2 shade cloth, east-west orientation) with compacted gravel in-situ floors. Feed bunks were 66 m in length, allowing for approximately 25 cm bunk space per head. Water troughs with float activated water supplies were 3 m long and shared between two pens. Fences were metal pipe with steel cabling.

Cattle began on a low concentrate starter diet and were adapted over the initial 10 days on feed to a high concentrate finisher diet of steam flaked wheat and barley that exceeded NRC 2016 requirements for beef cattle (National Academies of Sciences, Engineering and Medicine, 2016) with similar transition across experimental treatments. Cattle were fed twice per day with Laird-VS1400 commercial series feed mixer (Laird, Merced, California) with +/-5 kg scalehead breaks at (0600 – 0800 h and 1000 h – 1300 h) at consistent times for each block (±15 mins) for the duration of the experiment.

Duplicate dry matters were recorded daily by feedlot staff on the starter and finisher diets, by oven drying to constant weight for a minimum of 12 hrs at 100-120 C . Ration samples were collected weekly from across the trial pens, and a composite sample of each ration sent for laboratory analysis of the dry matter, crude protein, neutral detergent fibre, fat and ash each month (Symbio Laboratories, Brisbane, Australia).

Cattle were re-administered a HGP implant containing 20 mg estradiol-17β and 200 mg trenbolone acetate (Component TE200 with Tylan; Elanco Australia, Sydney) at day 42-45. Cattle were weighed individually the chute (Thompson Longhorn) in contiguous pen order to ensure no bias of time of feeding.

At the conclusion of the feed period (107 to 113 days on feed), each unique block of cattle was transported from the feedlot at an equivalent days on feed endpoint to a large commercial abattoir in trucks with 60 head capacity. All cattle from each block were transported to the abattoir on the same day. Final body weight of each pen was obtained using the truck weighbridge which had +/- 1 kg scale breaks. Treatments remained separate during lairage. Loading, dispatch, transport, unloading, and penning of cattle were audited. The distance of transportation was 207 km, and the duration of transportation was approximately 180 minutes.

At the abattoir, cattle remained in their treatment groups in unshaded lairage pens with dirt floors at a stocking density of approximately 2.3 m^2 per animal. Cattle remained in their lairage pens overnight and were not provided feed or hay during transportation and lairage, but had ad-libitum access to clean water. Cattle received a gentle belly wash of non-potable water from spray nozzles on the concrete-floored abattoir holding pens for 30 minutes, approximately 2 hours before slaughter. Fifteen minutes before slaughter, cattle received an additional potable water wash delivered from overhead in a holding yard for approximately 30 seconds.

Cattle were stunned with a non-penetrative stunner and processed according to industry standards including administering of the Aus-Meat hot carcase weight standard trim (AUS-MEAT Limited, Brisbane, Australia). Electronic radio frequency identification, time of stun, visual identification, and body number were recorded. All animals were graded under Aus-meat and Meat Standards Australia (MSA) grading standards at a minimum of 12 h chilling post-slaughter at -1 to 7 C.

3.5 Bunk calling procedure

Feed remaining calls for all treatments were made at 0200 h and 0500 h on all trial pens. Bunk calling staff used a maximum speed of 10 km/h during pen scanning. Only the control treatment bunk was viewed to allow the bunk caller to estimate the feed amount remaining manually. This process took, on average 2h from the beginning to the end of each bunk call. The bunk callers were blinded to the scanned feed volumes bunk side to not bias their manual calls and were provided with this data after the feed remaining call at the office. For the semi-automated treatment, the bunk callers used the scanning data along with any manual notes on cattle behaviour to make their daily decision on feed allocations at the office computer. For the fully automated treatment, the scanning data was manually imported into the bunk management algorithm to determine the daily allocation. For the experiment at total of 2 nightwatchman with 4 years experience facilitated the 0200 h call. A total of 3 feed allocators with 4 years' experience facilitated the 0500 h call. Mid way through the study, one bunk caller facilitating the 0500 h call was promoted to a new position at the feedlot and was replaced by a bunk caller with 2 months training.

All treatments had their bunks 'wet feed' swept following a significant rain event, and 'mould feed' swept after a pen failed to clean up their feed 2 days in a row, as was the standard procedure at the host site. 'Mould' sweeping occurred prior to the 0500 h bunk call so residual feed could not be scanned and measured.

The ration density was required to convert the volume of feed remaining into masses (kg). This was achieved by scanning the bunks of 5 pens per ration immediately after the feed was delivered. Then, the volume measurements and feed truck scale outputs were used to calculate an average ration density. Densities were calculated and adjusted each week and after each ration change for the trial duration.

3.6 Animal health

The animals in each pen were monitored by health (once daily) and nutrition (twice daily) teams comprised of individuals with expertise in animal monitoring and assessment. The animal health team entered each pen in the morning (0530 h – 1000 h) and inspected all individuals for health and wellbeing. The nutrition team inspected the pen and animals a minimum of two times a day for feed allocation, hygiene, water quality and quantity, and animal wellbeing.

Animals that required medical treatments were treated in the feedlot hospital system and were returned to the home pen when deemed fit by the animal health team. Hospital head days were recorded. Buller's were removed from the trial on the day that they were pulled from the home pen due to difficulties returning them to their original pens. Each day, animal health data, including hospital treatments, mortalities and bullers, were recorded. Morbidity was calculated based on an animal requiring one or more hospital treatments.

At 42-45 equivalent days on feed, the cattle in each block were weighed and re-implanted with a HGP as defined above. Any cattle in the hospital system on this day were not re-implanted.

Animals that were deemed unfit to return to their trial pens by the animal health staff or animals in the hospital system when their cohort exited the feedlot were deemed "rejects".

3.7 Performance and feeding measurements

Each day, electronic records of As-Fed feed deliveries and ration type (DM, NEm, NEg), daily headcount, feeding times, bunk caller ID and bunk scans of feed remaining were kept.

Cattle were individually weighed at induction and re-implant. Final body weight was recorded by weighing cattle over the on-site truck weighbridge at exit. Adjusted final bodyweight was calculated from hot carcass weight, adjusted for the average dressing percent of each block. The average dressing percent was calculated by the average hot carcase weight divided the average on-site truck weighbridge exit weight for each of the seven blocks.

Performance was calculated on a deads, bullers and rejects out basis for each treatment pen. Pen data were reported on a per head basis for statistical analysis. Feed and head days for deads, bullers and rejects was excluded from the analysis by calculating the average DMI for the DOF each individual head spent in the home and hospital pen and removing that quantity relative to the individual animals head days. All body weights reported are non-fasted body weights and are not pencil shrunk for digestive tract fill.

Calculations

Pen dry matter intake (kg/hd) = (home pen dry matter delivered for slaughtered animals kg + hospital pen dry matter delivered for slaughtered animals kg)/(home pen head days for slaughtered animals kg + hospital pen head days for slaughtered animals kg)

Pen initial body weight (kg/hd) = (pen initial body weight for slaughtered animals kg)/(pen head slaughtered)

Pen reimplant body weight (kg/d) = (pen body weight at reimplant kg)/(pen head reimplanted)

Pen final body weight (kg/d) = (pen truck exit weight for slaughtered animals kg)/(pen head slaughtered)

Pen average daily gain (kg/hd) = (pen truck exit weight for slaughtered animals kg - pen initial body weight for slaughtered animals kg)/total head days for slaughtered animals

Pen Feed:Gain ratio = (home pen dry matter delivered kg for slaughtered animals + hospital pen dry matter delivered for slaughtered animals kg)/ (pen truck exit weight for slaughtered animals kg - pen initial body weight for slaughtered animals kg)

Pen hot carcase weight (kg/hd) = (pen hot carcase weight kg)/(pen head slaughtered)

Pen dressing percent = (pen hot carcase weight kg)/(pen truck exit weight for slaughtered animals kg)

Pen adjusted final body weight (kg/hd) = (pen truck exit weight for slaughtered animals kg/[mean block dressing percentage/100])/Pen head slaughtered

Pen adjusted average daily gain (kg/hd) = (pen adjusted final body weight kg - pen initial body weight for slaughtered animals kg)/total head days for slaughtered animals

Pen adjusted Feed to gain ratio = pen dry matter intake/(pen adjusted final body weight - pen initial body weight for slaughtered animals)

Mortality, % = (head dead)/(head inducted into experiment) x 100

Morbidity, % = [(unique head treated once or more in hospital)/(head inducted into experiment)] x 100

Bullers, % = [(unique head removed due to buller syndrome)/(head inducted into experiment)] x 100

Reject, % = [(rejects)/(head inducted into experiment)] x 100

3.8 Carcass measurements

Hot standard carcass weight was recorded after evisceration and trimming. After chilling, carcass assessment was conducted by trained plant graders. Body number, dentition, left side bruise, right side bruise, left hot standard carcass weight, right hot standard carcass weight, total hot standard carcass weight, eye muscle area at the M. longissimus dorsi quartering site, pH at chiller assessment at the M. longissimus dorsi quartering site, subcutaneous rib fat cold at the M. longissimus dorsi (Aus-meat standard site), Aus-meat meat colour, P8 fat, hump height cold, and ossification were recorded. Dressing percentage was calculated as the total hot carcass weight divided by total exit weight times 100. In line with MSA grading procedures, carcass's which had a meat colour score greater the 3, or carcass pH greater than pH 5.7 were considered as dark cutting.

3.9 Statistical analysis

Pen was the experimental unit for all analyses. Performance data was analysed as a randomised block design with the random effect of block utilising the PROC MIXED procedure of SAS. Least square means were separated utilising PDIFF, protected by an F Test ($P \leq 0.05$). The proportion of morbidity and mortality data was analysed as a binomial proportion using the PROC GLIMMEX procedures of SAS with block as a random effect.

4. Results

4.1 Performance results

Analysed least square means for the measured performance outcomes are presented in Table 1. Compared to the control group utilising traditional bunk management, there were no differences ($P>0.05$) between the semi or full-automation treatments for the key performance outcomes.

No differences ($P>0.05$) were observed for weight gain at re-implant and feedlot exit between treatments. Dry matter intake (DMI) for the control group was not different ($P>0.05$) from the semi and full-automation treatments over the full feeding period. However, from zero DOF to reimplant, the control and semi-automated group had a higher DMI than the control ($P=0.035$). From reimplant date to feedlot exit, the control and full-automation treatments had higher DMI than the semi-automated group ($P=0.001$). There were also no differences between treatments for feed efficiency across the 109 days on feed (Feed:Gain ratio).

4.2Treatment on 10-day interval feed intake

The average DMI for each treatment was analysed in to 10-day intervals from induction date to exit date and is shown in Table 2. When broken down into 10-day feeding intervals, the full-automation treatment had a lower DMI than the control and semi-automation treatments from 0-9 DOF ($P=0.021$) and 10-19 DOF ($P=0.010$). From 20-49 DOF, there was no significant difference in DMI between treatments. From 50-59 DOF ($P=0.009$), 60-69 DOF ($P=0.0003$), 70-79 ($P=0.0004$) DOF and 90-99 DOF ($P=0.012$), the control and full automation had a higher average DMI than the semi-automation treatment.

4.3 Carcass results

The descriptive statistics for the key carcass outcomes are shown in Table 3. For the characteristics of hot carcass weight (HCW), dressing percentage, P8 fat, MSA rib fat depth, MSA marbling score, hump height and ossification, there was no difference (P>0.05) between the control and semi and full-automation treatments. Eye muscle area (EMA) was greater for the control group than both the semi and full-automation treatments (P=0.046). However, this difference in EMA is less than 1% and requires further research to confirm with confidence.

4.4 Health results

The descriptive statistics for the key health outcomes for research population are shown in Table 4. There was no difference across the three treatments (P>0.05) for morbidity, mortality and bulling percentage. There were no differences between the treatments (P>0.05) for meat colour score (>3), carcass pH (>5.7) and, therefore, overall dark cutting percentage. As bullers were all excluded from the trial once pulled from the home pen, morbidity and mortality of bullers post-trial exit was not included.

Table 1. Effect of semi & full automation of bunk management on cattle performance

	Treatment				
Performance	**Control**	**Semi-Automation**	**Full-Automation**	**SE**	**P-value**
Days on feed	109.0	109.0	109.0	1.00	0.728
Initial BW (kg)	420.3	419.8	420.4	2.91	0.816
Reimplant BW (kg)	519.6	517.0	518.7	3.15	0.426
Final BW, kg	640.2	634.4	637.2	6.06	0.158
Adjusted Final BW (kg)	639.6	634.3	638.0	6.58	0.184
ADG (kg/d)	2.02	1.97	1.99	0.08	0.073
Adjusted ADG (kg/d)	2.01	1.97	2.00	0.082	0.102
DMI (kg/d)	10.63	10.45	10.50	0.180	0.060
DMI - 0DOF-Reimplant (kg/d)	9.87^{a}	9.81^{a}	9.48^{b}	0.166	0.035
DMI - Reimplant - Exit (kg/d)	11.14^{a}	10.87^{b}	11.17^{a}	0.228	0.001
F:G	5.30	5.34	5.30	0.137	0.272
Adjusted F:G	5.31	5.35	5.28	0.138	0.212

SE = standard error of treatment means; n = 7 pens per treatment

Table 2. Effect of semi & full automation of bunk management on pen dry matter intake (kg/d) segmented into 10 DOF intervals

	Treatment				
	Control	Semi-Automation	Full-Automation	SE	P-value
DMI 0-9 days	7.18[a]	7.17[a]	6.72[b]	0.140	0.021
DMI 10-19 days	9.32[a]	9.32[a]	8.51[b]	0.223	0.010
DMI 20-29 days	10.51	10.35	10.07	0.219	0.106
DMI 30-39 days	10.97	10.85	10.86	0.252	0.594
DMI 40-49 days	10.92	10.67	10.89	0.224	0.210
DMI 50-59 days	11.30[a]	10.99[b]	11.26[a]	0.197	0.009
DMI 60-69 days	11.41[a]	10.86[b]	11.43[a]	0.219	0.000
DMI 70-79 days	11.29[a]	11.04[b]	11.40[a]	0.204	0.000
DMI 80-89 days	11.00	10.77	11.00	0.276	0.088
DMI 90-99 days	10.78[a]	10.55[b]	10.79[a]	0.284	0.012
DMI 100-109 days	10.64	10.40	10.68	0.353	0.192

[abc]Means with superscripts differ (P ≤ 0.05)
SE = standard error of treatment means; n = 7 pens per treatment

Table 3. Effect of semi & full automation of bunk management on economically relevant carcass characteristics

	Treatment				
Carcase	**Control**	**Semi-Automation**	**Full-Automation**	**SE**	**P-value**
HCW (kg)	351.4	348.5	350.5	2.77	0.183
Dressing percent, %	54.90	54.93	55.01	0.133	0.477
P8 Fat (mm)	14.27	14.33	14.56	0.301	0.319
MSA rib fat (mm)	10.70	10.78	11.03	0.314	0.196
EMA (cm2)	82.58[a]	81.78[b]	81.81[b]	0.694	0.046
MSA marbling	344.68	337.85	342.01	3.466	0.261
Hump Height (mm)	118.11	118.27	116.76	5.230	0.564
Ossification	210.71	214.81	213.47	7.791	0.098

[abc]Means with superscripts differ (P ≤ 0.05)
SE = standard error of treatment means; n = 7 pens per treatment

Table 4. Effect of semi & full automation of bunk management on key cattle health characteristics

	Treatment				
Morbidity & Mortality	**Control**	**Semi-Automation**	**Full-Automation**	**SE**	**P-value**
Morbidity (%)	6.59	6.31	6.16	*	0.843
Mortality (%)	0.16	0.38	0.49	*	0.295
Buller (%)	2.57	2.45	2.40	*	0.945
Reject (%)	0.49	0.60	0.71	*	0.707
Meat Colour >3 (%)	4.18	4.44	3.92	*	0.756
pH >5.70 (%)	0.28	0.40	0.35	*	0.848

SE = standard error of treatment means; n = 7 pens per treatment

5. Discussion

The objectives of this study were to develop a framework that can allow for the automation of bunk management in a commercial setting and then determine the feasibility of automating bunk management on performance and health outcomes. The results indicate that bunk management can be automated to reach equivalent health and performance outcomes of a highly skilled bunk caller.

Accurate predictions of feed intake are critical for the feedlot industry, as daily fluctuations in feed intake can reflect a change in pen health status (González et al., 2012), issues with the manufacture of the diet, and are key for the calculation of nutrient requirements, diet formulation and daily allocations (Pahl et al., 2016). In traditional bunk management, bunk calling accuracy relies heavily on the experience and ability of the bunk caller to quantify their visual observations correctly, and inconsistency between bunk calling staff can result in feed delivery fluctuations (Dorea and Cheong, 2019, McCarthy et al. 2018 ab).

Feedlots make a significant effort in training their bunk calling staff as these individuals are a key driver of performance and profit in the yard. However, regardless of the experience of the bunk caller, situations can arise where poor decisions can be made.

Three experiments validated the scanning technology used in the current study in commercial feedlots (McCarthy et al. 2018b). The bunk calling prototype provided highly precise and accurate feed remaining predictions across the 3 sites and significantly outperformed the human bunk callers, particularly as mass increased.

Previous research on determining feed intake has predominantly focussed on systems where animals are fed individually, incorporating scales placed under bunks (Bach et al., 2004, Chizzotti et al., 2015, Wang et al., 2021), or using active 3D imaging technologies (Lassen et al., 2018, Shelley et al., 2016). Limited industry uptake is attributed to the high capital cost of setting up the system, frequent maintenance and additional infrastructure requirements, making them impractical (Tedeschi et al., 2021).

The proposed scanning unit used for this study is specifically designed for use in Australian feedlots as the system is mobile, can accurately measure large amounts of feed, has relatively low infrastructure requirements, and has led to the development of a prototype autonomous vehicle to be able to record uncrewed measurements of feed remaining in a commercial feedlot (McCarthy et al. 2019). The results from this trial show that semi and full automation is highly feasible for Australian feedlots and can be used to reach equivalent performance, health and carcass outcomes as a highly-skilled human bunk caller. The additional key benefits include providing accurate feed remaining information for bunk calling staff with less experience or during times of staff turnover and could reduce the risk of poor bunk call decisions. The use of scanning data also would provide management with accurate data on the feed consumption across the entire yard.

The semi-automation group had lower DMI than the control and full automation from 50-79 DOF and 90-99 DOF is hypothesised to be due to overcutting (i.e., reducing feed offered) cattle causing them to have a slower return to full feed intake. The methodology for cutting cattle at the trial site was to double the feed remaining and subtract that amount from the previous day's allocation when cutting cattle that had left feed in the bunk on two consecutive days. It is hypothesised that with the increased accuracy of the bunk scanning data, 'double cutting' the cattle led to overcutting, causing cattle to take more time to return to a high DMI level. For this reason, it is recommended that specific guidelines be followed when bunk calling using accurate scanning data as opposed to traditional bunk calling procedures.

Automated feeding systems have been limited to dairy production, where ad-libitum feed is delivered at a predetermined amount each day (Grothmann et al., 2010). The difficulty involved in automating bunk management is that the total feed delivered needs to be monitored and often adjusted daily to ensure high performance and prevent metabolic disorders. In order to fully automate bunk management, an algorithm was developed to incorporate scanning data and various other factors to determine the daily feed allocation.

The full automation treatment performed as well as a highly-skilled bunk caller for performance, health and carcass characteristics as a highly-skilled bunk caller. Interestingly, During the first 19 DOF, the control and semi-automation groups outperformed the full-automation treatment in daily DMI (Table 2).

There are a number of potential hypothesise for this; firstly, it was determined that due to feeding cattle with a high Bos indicus content, each block was assigned a breed adjustment factor between 0.9 and 0.95 based on recommendations by the National Academies of Sciences and Medicine (2016) that Bos indicus breeds require up to 10% less energy for maintenance than Bos taurus cattle, with crossbreeds intermediate. Secondly, the first 4 blocks of cattle inducted into the trial experienced high levels of compensatory gain and were consuming significantly higher DM/day for the first 19 days. For these reasons, the full-automation treatments had lower DMI over the first 19 days than the control and semi-automation as the algorithm was ‘energy capped’ and as such, could not adjust to the unexpectedly high feed appetite limiting maximum intake versus control and semi-automated treatments. This confirms the indication that the algorithm can be further refined to improve cattle production outcomes in the future.

The end product of feedlot production is the animal carcass. This study saw no differences (P>0.05) in key carcass characteristics (Table 3). This is also promising for the potential for the future automation of bunk management as it gives producers confidence that their end product will be comparable the cattle fed under traditional bunk management strategies.

Consumers have a high level of concern related to animal welfare and environmental sustainability and finding methods to improve feedlots practices will benefit livestock and the industry at large (Schwartzkopf-Genswein and Moya, 2015). As stated by (Tedeschi et al., 2021), "Feed cost represents as much as 65% to 75% of the operational expenses in intensive dairy or beef operations". Therefore, it is important that there were no decreases in feed efficiency for either of the automation treatments and control. In addition to this, the goal of future research into the automation of bunk management should be targeted at improving DMI and improving the feed efficiency of feedlot cattle to improve the sustainability of the feedlot cattle and red meat industry.

As mentioned above, promoting animal health and welfare is a critical component of feedlot production. The results from this study indicate that automation had no impact ($P>0.05$) on key health parameters, including mortality, morbidity and bulling percentage, compared to the control. An automation system must be reliably able to ensure good health and welfare for any feedlot that implements such technology; therefore, the results of this study on health parameters are promising.

Further research is needed to establish the feasibility of algorithm refinements to improve performance and efficiency, along with providing an economic return. It should also be noted that for the adoption of automated bunk management technology, incorporation with feedlot integrated management software.

6. Conclusion

Semi and full automation of bunk management was found to be as effective at achieving cattle daily gain, feed conversion and exit weight across the whole feeding period as a highly-skilled bunk caller. Moreover, semi and full automation of bunk calling did not negatively impact animal health parameters, mortality, or economically relevant carcass values.

In conclusion, Bunk-management can be automated to allow cattle to reach equivalent performance and health status as a highly-skilled human bunk caller. An automated bunk management system has the future potential to deliver performance, health & economic benefits to Australian feedlots by improving the accuracy of feed intake information and consistency of bunk calling.

6.1 Key findings

- Semi and full automation of feed calling was as effective as very highly trained bunk callers in achieving cattle daily gain, feed conversion and exit weight.
- Automation of feed calling (semi and full) did not negatively impact any animal health parameters, mortality, or economically relevant carcass value.
- The control and semi-automation treatments had a higher DMI intake between the periods of induction and re-implant, specifically the first 20 days.
- From re-implant to exit, the control and full-automation treatments outperformed the semi-automation treatment for feed intake (DMI).
- Opportunities for minor algorithm refinements have been identified.

6.2 Benefits to industry

6.2.1. Development of a framework to automate bunk management

This study shows that bunk management can be automated to achieve the same health and performance results as a highly-skilled bunk caller. The development of such a framework is a world first and has the potential to improve how we feed cattle. Developing an automated bunk management system to the level of a highly skilled caller opens up the door to feedlots to automate part or their entire bunk management system to a very high decision-making standard. The framework can also be easily adapted and customised for the individual feedlot needs. This will improve the decision-making process around feed allocation.

In the future, yards would have the option to automate parts or the entire bunk management system to reduce the pressure on staff, improve consistency between roster changes and staff turnover, and provide reliable data back to management and nutritionists. All of which will improve the efficiency of the feedlot operations.

6.2.2. Semi-automation and accurate determination of feed remaining

Previous studies by MLA (B.FLT.7009, B.FLT.0166) showed that the bunk scanning system is highly precise and accurate at determining the feed remaining in a bunk. In contrast, the human callers provide significantly less accurate and precise estimates of feed remaining in the bunks, especially when large amounts of feed were not eaten. By scanning the bunk instead of manually reading, the bunk caller has more time to assess the available feed intake history data and make a well-informed decision on the day's allocation. This added accuracy benefits both the bunk caller and feedlot management. A higher accuracy, particularly on first bunk calls where amounts of feed remaining are larger than that at the allocation call, provides the bunk caller with reliable information on what the cattle have consumed, when feed is remaining, how much to manage feed allocations to ensure that cattle return to appropriate feed intakes in a timely manner, with no feed related health issues.

Management could also benefit from more accurate feed remaining determination, as it provides a risk mitigation tool. Management and nutritionists could be confident of exactly how much feed remains at both calls and can reduce the risk of potential losses from cattle cleaning up their feed early, resulting in extended time without available feed, potentially reducing daily gains.

An additional benefit to implementing a semi-automated system to determine the feed remaining in bunks accurately provides data on the actual feed consumption for the past 24 h that was previously unavailable to management and nutritionists. This data on what the cattle have eaten rather than what was delivered could allow for more informed decisions regarding daily allocations and feed wastage.

Semi-automation needs to be considered differently from conventional bunk calling in terms of the protocols in place for bunk callers to follow, particularly when it comes to 'cutting' feed. Feedlot staff and nutritionists will need to adjust their rules to fully utilise the information with more accurate information.

6.2.3. Full-Automation

A fully automated bunk management system would have all of the benefits of a semi-automated scanning system, with additional benefits for staff, management, and potentially with refinements, performance, and health benefits. The flexibility of the system means that yards could use the allocation software as a decision support tool for bunk calling staff, providing a “second opinion” that could assist decision making when staff are unsure, and help to reduce the incidence of poor decisions. Feedlots could also fully automate the bunk call with the software making all of the allocation decisions – possibly with- or without- human oversight, freeing up staff to undertake other duties.

Either way, allowing for more accurate and consistent decision making on allocation has the potential to improve feeding consistency across the entire yard and aid during times of difficulty such as staffing turnovers, staff training or inclement weather.

The starter phase for cattle is a particularly delicate period, and if cattle are over-allocated feed before their rumen has acclimated to the high starch diets, severe digestive disturbances and drops in feed intakes can occur, which can negatively impact the whole growing period. The fully automated system prevents overallocation during the first 20 days on feed with cattle intakes capped. This would reduce the incidence of pushing cattle to hard during the adaption phase and ensure they fully acclimated to the new diets and are in a good state to have high intakes across the finisher phase. On the other hand, potential losses in production can often occur when cattle are not pushed hard enough during the finisher phase with staff holding cattle for too long or only increasing feed slightly but not enough to have a metabolic impact. Future research on improving the automation process for performance and health benefits is highly recommended.

6.2.4. Performance and Health

With future improvements to both the algorithm scanning technology, it can be assumed that there is a high potential for the automation of bunk management to provide performance and health benefits in feedlot production and an overall economic benefit in terms of improving the consistency of feed allocation decisions over the full feeding cycle. Therefore, minimising subclinical acidosis, reducing the pressure on staff and freeing up more time for other tasks, and providing management and nutritionists with greater amounts of accurate data on feed consumption to prevent potential losses in feed intake.

6.2.5. Research

Future research in the beef industry has the potential to utilise a fully automated bunk management system at research or commercial feedlots in order to remove the variability that can occur when one or more bunk callers are used. This would ensure that all treatments follow the same feeding regimen and eliminate the impact of mistakes or poor decisions that could influence research outcomes.

7. Future research and recommendations

- Identify and implement algorithm refinements
- Incorporation into integrated feedlot production software
- Further validation of refined algorithm with aim at providing an economic benefit
- Evaluation under different climatic conditions and cattle breeds

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