final report

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Prototype development for sensor technologies to automate feedlot bunk management

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Executive summary

Feed bunk management is the process of determining feed allocation for pens of feedlot cattle for a 24-hour feeding cycle. Objectives of bunk management include consistently maximising feed intake, whilst minimising feed wastage and digestive disorders (bloat and acidosis). Bunk calling is a critically important job, and the human callers' actions directly determine feed intake and carcase weight gain of pens of feedlot cattle.

It is now feasible to automate feed bunk management with advancements in mapping, sensors, and robotics technologies. A prototype was designed and validated to quantity feed remaining in bunks at Mort & Co's Grassdale Feedlot, Queensland, Australia. The vehicle-mounted prototype's primary sensing element is based on light detection and ranging (lidar) technology. The on-board positioning solutions determine where the vehicle is in a world coordinate system. An on-board attitude solution accounts for any vehicle roll and rock and any other dynamic events to improve the quality of the data collected. The scanner has an on-board computer that measures and integrates the data as it travels along the bunk, publishing a volume of feed remaining at the end of each bunk. Given density of the different rations, feed remaining in the bunks is determined. Utilising lidar technology the bunk scanner can work in day and night conditions.

Two experiments evaluated the precision and accuracy of the prototype to quantify feed remaining in bunks. Experiment 1 utilised a 33 m length of preformed concrete bunk placed on a compacted gravel pad (test bunk), adjacent to the operational feedlot. Ten random quantities (0 to 905 kg) of a steam-flaked wheat-based finisher diet were weighed into the bunk during day and night conditions. Both bunk callers and engineers operating the bunk scanner were blinded to this process. For each graded level of feed, bunk callers (two humans for day; one human for night) independently estimated feed remaining from a utility vehicle. The prototype bunk scanner mounted to a separate vehicle then conducted three scans of the bunk for each graded level of feed to determine feed remaining.

Under both day and night conditions the prototype system accurately and precisely predicted feed remaining in bunks, outperforming human callers in both criteria. The prototype had small amounts of mean bias (*P-values* ≤ 0.01); over (-8.3 kg) and underestimating (5.9 kg) feed remaining for day and night measurements, respectively. The prototype had no linear bias (*P-value* = 0.906) during day conditions i.e. bias was consistent over the full range of feed remaining in the bunk. For night conditions, significant linear bias was reported (*P-value* = 0.008), however the magnitude was small (10.4 to -3.4 kg). Precision of the prototype was excellent under both day and night conditions (r^2 = 0.99). Mean absolute error for the prototype system was 11.6 and 9.1 kg for day and night, respectively.

Human performance was variable and less accurate. Larger amounts of significant mean bias (*P-values* ≤ 0.01) were reported with bunk callers over (-47.5 kg) and underestimating (161.0 kg) feed remaining for day and night measurements, respectively. Significant linear biases (*P-values* ≤ 0.01) were reported, with the magnitude being much larger than the prototype (-1.9 to -148.0 kg for day bunk callers; -71.7 to 514.3 kg for night bunk callers). Mean absolute error for human callers was 49.5 and 162.0 kg for day and night, respectively. Precision of human callers was however sufficient (r^2 = 0.98 and 0.96 for day and night, respectively).

Experiment 2 evaluated the performance of the newly validated prototype system in an operational feedlot over two weeks in daylight conditions. The designated bunk caller for the day, and the prototype determined feed remaining in the early morning (0600 hours) prior to feeding. Feed was then vacuumed from each bunk and weighed back. A total of 55 bunks were measured with feed weights from 0 to 330 kg. The baseline geometry for all assessed bunks was unknown prior to estimation of feed remaining. Accordingly, a second pass of the prototype scanner occurred immediately after

weighing and vacuuming to determine profiles for empty bunks. Quantity of feed remaining was determined from post-processing of lidar point-cloud data.

The prototype outperformed humans for precision and accuracy of estimation of feed remaining under commercial operating conditions. The prototype had small amounts of mean bias (*P-value* ≤ 0.01) underestimating feed delivered on average by 11.3 kg. Linear bias was not significant (*P-value* > 0.05) however a trend for linear bias of a small magnitude was observed (8.7 to 20.2 kg). Supporting this, linear or systematic bias accounted for only 3.14% of the decomposition of the mean square prediction error. Precision was again excellent (r^2 = 0.98). Mean absolute error for the prototype was 12.2 kg. It is believed than the mean bias detected in this experiment is possibly the result of changes in density from when the feed is delivered, to when the bunks are called 24 hours later. Settling and compaction could be attributable to the feeds duration in the bunk, as well as the livestock interaction with feed. Simple offsets to accounts for this mean bias will likely improve the accuracy of the bunk scanner and require further investigation.

In contrast, human callers had increased mean bias (*P-value* ≤ 0.01) underestimating feed remaining by 34.6 kg. Significant linear bias (*P-value* ≤ 0.01) was observed (12.6 to 115.8 kg), with bias increasing with quantity of feed remaining in the bunk. This makes biological sense given the challenges of estimating large quantities of feed in bunks. Precision was satisfactory for human bunk callers (r^2 = 0.78) but not superior to the prototype under commercial operating conditions. Mean absolute error reported for humans was 37 kg; approximately 2.8 times that of the prototype.

Based on the results of project, the prototype bunk scanner demonstrates exciting promise to determine feed remaining in bunks, with performance superior to human operators. Further extended campaigns of measurement are required across diverse feedlot sites to determine the robustness of the prototype versus human observation. We believe this to be a world-first application of the aforementioned technology that paves the way to objective automation of bunk management and represents a high-value outcome for the Australian feedlot industry.

Table of contents

1 Introduction

This final report describes the results of two experiments to evaluate a prototype bunk scanner to estimate feed remaining in bunks of feedlot cattle.

1.1 Automation of bunk management

Feed bunk management is the process of determining feed allocation for pens of feedlot cattle for a 24-hour feeding cycle. Objectives of bunk management include consistently maximising feed intake, whilst minimising feed wastage and digestive disorders (bloat and acidosis). Bunk calling is a critically important job, and the human callers' actions directly determine feed intake and carcase weight gain of pens of feedlot cattle.

The process of bunk management is currently 'subjective' and is often described as more of an art, than a science. Part of the reason for this is estimation of feed remaining in bunks is made by humans, who are unique in their cognitive functions. No formally published literature exists evaluating the precision and accuracy of humans to estimate feed remaining, partly due to the labour-intensive process of weighing back quantities of feed from bunks. Experienced managers in commercial feedlots report variation between bunk callers in estimation of feed remaining, which is influenced by previous training, skill level, and focus on any given work day. The value proposition of decreasing variation between bunk callers remains to be determined.

To pave the way for automation of bunk management, 'objective measurement' of feed remaining is the first challenge to overcome.

1.2 Prototype design – bunk scanner

It is now feasible to automate feed bunk management with advancements in mapping, sensors, and robotics technologies. A prototype was designed and validated to quantity feed remaining in bunks at Mort & Co's Grassdale Feedlot, Queensland, Australia. The vehicle-mounted prototype's primary sensing element is based on light detection and ranging (lidar) technology. The on-board positioning solutions determine where the vehicle is in a world coordinate system. An on-board attitude solution accounts for any vehicle roll and rock and any other dynamic events to improve the quality of the data collected. The scanner has an on-board computer that measures and integrates the data as it travels along the bunk, publishing a volume of feed remaining at the end of each bunk. Given density of the different rations, feed remaining in the bunks is determined. Utilising lidar technology the bunk scanner can work in day and night conditions.

2 Project objectives

1. Develop a prototype vehicle mounted sensor system to estimate feed remaining in bunks of feedlot cattle.
2. Determine the precision and accuracy of the prototype to estimate feed remaining for finisher diets.
3. Determine the precision and accuracy of human bunk callers to estimate feed remaining for finisher diets.

3 Methodology

The project was conducted at Mort & Co Grassdale feedlot, near Dalby, Queensland, Australia. Grassdale is a modern feedlot facility and is currently expanding to 70,000 standard cattle units. Two experiments evaluated the precision and accuracy of the vehicle mounted prototype to quantify feed remaining in bunks.

3.1 Experiment 1 – test bunk

Experiment 1 utilised a 33 metre length of preformed concrete bunk placed on a compacted gravel pad (test bunk), adjacent to the operational feedlot (See Figure 1). Ten random quantities (between 0 and 905 kg) of a steam-flaked wheat-based finisher diet were delivered into the bunk during day and night conditions. Masses up to 110 kilograms were hand weighed on a platform scale (CAS BW-L60, Brisbane, QLD; ±0.1 kg readability). Weights more than this were delivered by a paddle mixer (Rotomix 920-18; Dodge City, KS, USA) and its scale-head (Digistar EZ indicator; Fort Atkinson, WI, USA; ±5 kg readability). Both platform and feed truck scale were calibrated and check-weighed prior to the commencement of the experiment. An independent facilitator generated these amounts, to blind bunk callers and project engineers from the amounts delivered and supervised their delivery by other independent staff.

For each graded level of feed, bunk callers (two humans for day, 'A' & 'B'; one human for night, 'C') were asked to estimate feed remaining from a light utility vehicle (Landcruiser, Toyota, Japan) and was blinded to the other bunk callers' estimations of feed remaining. The prototype bunk scanner attached to the tray of a separate light utility vehicle (Hilux, Toyota, Japan) then conducted three scans of the bunk for each graded level of feed to determine the volume remaining. Travel speeds for both vehicles were approximately 10 km/hr. Weather conditions for the experiment were dry during January 2018.

Figure 1. The typical human caller activity for estimating feed remaining in the test bunk.

Feed density for this experiment was determined from a quotient calculated from the known feed mass delivered for the maximum observed feed quantity divided by the predicted volume, averaged over three passes. The quotient was multiplied by scanned volume to determine feed remaining.

3.2 Experiment 2 – operational feedlot environment

Experiment 2 evaluated the performance of the newly validated prototype system in an operational feedlot environment. The study site was 0.7 km by 1.59 km, and road surfaces in feed alleys were bitumen. As a preliminary activity, the start and end positions of all pens was georeferenced, i.e. located in global coordinates based on GNSS measurements from the rover, to enable automatic localisation within the feedlot during this experiment. Three bunk callers were utilized for Experiment 2 over the ten days of measurement (‘A’ for two days, ‘B’ for three days, and ‘D’ for five days). Bunk callers utilised the Toyota Landcruiser utility previously described in Experiment 1, and drove at commercial operating speeds between 10 and 25 km/hr. Weather conditions were dry during Experiment 2 in late January 2018.

Only pens delivered finisher diet during day light hours (steam-flaked wheat-based) were utilised for this experiment. Over the experiment’s two-week duration, five observations per day were made in week one, and six per day in the second week; a total of 55 observations from slick bunks (0 kg) to 330 kg remaining. Feed remaining quantities were scaled based on pen head-counts, with a view of completing a representative and evenly distributed dataset from 0 to greater than 1 kg/head remaining in the feed bunk. Measurements were taken from 34 unique feed bunks, from pens in the 1^{st}, 8^{th}, 9^{th}, 10^{th}, 11^{th}, and 12^{th} rows of the feedlot. Bunks ranged in length from 21.7 to 88.0 m with an average length of 52.3 m and a standard deviation 21.6 m.

The designated bunk caller for the day and the proto-type bunk scanner determined feed remaining independently in the early morning (starting at 0600 hrs) prior to feeding. The utility with the bunk scanner was operated at approximately 10 km/hr. Feed was then vacuumed from each bunk (Greystone Maxi Vac, Bells Creek, Q, Aus). The collected feed remaining masses were dumped onto segregated tarpaulins in a protected location in the feedlot away from normal operations and weighed on the platform scale previously described (See Figure 2).

Figure 2. Paddock vacuum contents being transferred to tarpaulins for later weigh-back and recording as observed feed remaining values.

The baseline geometry for all assessed bunks was unknown prior to estimation of feed remaining. Accordingly, a second pass of the prototype scanner occurred immediately after weighing and vacuuming to determine profiles for empty bunks. Volume of feed remaining was determined from post-processing of lidar point-cloud data.

The density of the delivered ration was also required daily to convert the prototype system's predicted feed remaining volumes to masses. The prototype bunk scanner measured delivered volume immediately after feed delivery (starting at 0700 hours). A feedlot staff member kept cattle away from the feed bunk so an accurate measurement of delivered volume could be determined. These predicted volume measurements and feed trucks' scale outputs were used to calculate the average daily density of the delivered ration, which in turn was applied to the day's volume predictions.

3.3 Statistical analyses

For Experiments 1 and 2, several statistical analyses were calculated to objectively assess the performances of the prototype system and human bunk callers.

Observed feed remaining was regressed on predicted feed remaining for both the prototype system and human bunk callers. The coefficient of determination (r^2) was calculated on the line of regression as a measure of the strength of the relationship between observed and predicted feed remaining.

Evaluation of the model's precision utilized several commonly used measures of deviance, including mean absolute error (MAE), mean square prediction error (MSPE), and root mean square error (RMSPE). Shah and Murphy (2006) defined MSPE as: $\Sigma (Oi - Pi)^2/n$, where n = number of paired observed (O) and predicted (P) feed remaining values being compared. The MAE is defined as: $(\Sigma|Oi - Pi|)/n$.

Furthermore, the MSPE was decomposed to assess sources of variation, viz, (1) variation in central tendency (mean bias), (2) variation resulting from regression (systematic bias or line bias), and (3) random variation. Variation resulting from mean bias was calculated by squaring the mean bias of the prediction, whereas variation resulting from systematic bias was calculated as the product of the variance of the predicted feed remaining and the square of the deviation from 1 of the slope of the regression of observed on predicted data. Random variation was calculated as the product of the variance of observed data and the deviation from 1 of the coefficient of determination of the regression of observed on predicted data. Shah and Murphy (2006) noted that mean bias is useful to test the robustness of the model, whereas line bias can be used to test inadequacy in model structure. Mean proportional bias has been calculated as the slope of the regression of the predicted data on observed data with an intercept of 0 (Shah and Murphy, 2006). Over the range of observed values, a value of mean proportional bias less than one (< 1) denotes underprediction, whereas a value more than one (> 1) denotes overprediction.

In addition, mean and linear biases were calculated by regression of residuals (observed minus predicted feed remaining) on mean-centred predicted feed remaining to assess model accuracy (St-Pierre, 2003). St-Pierre (2003) noted that by centring predicted feed remaining to the mean value, the intercept of the linear model is estimated at the mean value of the independent variable rather than a value of zero.

The intercept term at the mean value is a measure of the mean prediction bias, and a t-test on the estimate of the intercept has been used to determine the statistical significance of this bias. The slope of this mean-centred regression is an estimate of the linear prediction bias, and a t-test has been used again to test significance. When the linear prediction bias has been found to be significant ($P \leq 0.05$), the magnitude of the bias within the range of predicted values was determined by calculating the bias at the minimum and maximum data points of the predicted values (St-Pierre, 2003).

4 Results and Discussion

4.1 Experiment 1 – test bunk

The coefficient of determination (r^2) from regression of observed on predicted feed remaining for day and night experiments for humans and prototype system are detailed below in Table 1. Additionally, the mean and linear biases are reported from the regression of residuals on mean-centred predicted feed remaining.

Table 1. Evaluation statistics for estimation of feed remaining for humans and prototype system in Experiment 1 at the test bunk facility.

	Humans		**Prototype system**	
Item	**Day**	**Night**	**Day**	**Night**
Mean bias, kg	-47.500	161.000	-8.329	5.907
P-value	< 0.001	< 0.001	0.001	0.002
Linear bias	-0.146	1.674	-0.001	-0.015
P-value	< 0.001	< 0.001	0.906	0.008
r^2, regression of observed on predicted feed remaining	0.980	0.959	0.998	0.999
RMSPE, kg	80.172	258.370	14.832	11.904
MSPE, kg^2	6,427.500	66,755.000	219.973	141.717
MAE, kg	49.500	162.000	11.640	9.088
Mean proportional bias	1.162	0.409	1.014	0.998
Decomposition of MSPE				
Mean bias, %	35.10	38.83	31.54	24.62
Systematic bias, %	37.88	55.12	0.04	17.05
Random bias, %	27.02	6.05	68.42	58.33
Bias at minimum predicted value, kg	-1.918	-71.742	-	10.433
Bias at maximum predicted value, kg	-148.013	514.298	-	-3.414

Under both day and night conditions the prototype system accurately and precisely predicted feed remaining in bunks, outperforming human callers in both criteria. The proto-type had small amounts of mean bias (*P-values* $\leq$ 0.01); over (-8.3 kg) and underestimating (5.9 kg) feed remaining for day and night measurements, respectively. The prototype had no linear bias *(P-value* = 0.906) during day conditions i.e. bias was consistent over the full range of feed remaining in the bunk; it follows that minimum and maximum biases were not calculated. For night conditions, significant linear bias as reported (*P-value* = 0.008), however the magnitude of bias was small (10.4 and –3.4 kg at minimum and maximum predicted values, respectively). Precision of the prototype was excellent under both day and night conditions (r^2 = 0.99). Mean absolute error for the prototype system was 11.6 and 9.1 kg for day and night, respectively. The RMSPE was 14.8 kg during the day, and 11.9 kg at night.

Human performance was variable and less accurate. Larger amounts of significant mean bias (*P-values* $\leq$ 0.01) were reported with bunk callers over (-47.5 kg) and underestimating (161.0 kg) feed remaining for day and night measurements, respectively. Significant linear biases (*P-values* $\leq$ 0.01) were reported, with the magnitude being much larger than the prototype (-1.9 to -148.0 kg for day bunk callers; -71.7 to 514.3 kg for night bunk callers). Mean absolute error for human callers was 49.5 and 162.0 kg for day and night, respectively. The RMSPE was 80.2 kg during the day, and 258.4 kg during the night.

Human measurements across day and night were inconsistent (mean proportional biases of 1.162 and 0.409 respectively), albeit with reasonable levels of precision (r^2 of 0.98 and 0.96). The nightwatchman in this experiment significantly underestimated quantities of feed remaining in bunks at quantities over 1 kg/hd remaining in the bunk. This demonstrates the diversity of skills and inconsistency amongst humans in a large commercial feedlot versus the consistent prototype system.

4.2 Experiment 2 – operational feedlot environment

The prototype outperformed humans for precision and accuracy of estimation of feed remaining under commercial operating conditions (See Table 2). The prototype had small amounts of mean bias (*P-value* ≤ 0.01) underestimating feed delivered on average by 11.3 kg. Linear bias was not significant (*P-value* > 0.05) however a trend for linear bias of a small magnitude was observed (8.7 to 20.2 kg). Supporting this, linear or systematic bias accounted for only 3.14% of the decomposition of the mean square prediction error. Precision was again excellent (r^2 = 0.98). Mean absolute error for the prototype was 12.2 kg. It is believed than the mean bias detected in this experiment is possibly the result of changes in density from when the feed is delivered, to when the bunks are called 24 hours later. Settling and compaction could be attributable to the feeds duration in the bunk, as well as the livestock interaction with feed. Simple offsets to accounts for this mean bias will likely improve the accuracy of the bunk scanner and require further investigation.

In contrast, human callers had increased mean bias (*P-value* ≤ 0.01) underestimating feed remaining by 34.6 kg. Significant linear bias (*P-value* ≤ 0.01) was observed (12.6 to 115.8 kg), with bias increasing with quantity of feed remaining in the bunk. This makes biological sense given the challenges of estimating large quantities of feed in bunks. Precision was satisfactory for human bunk callers (r^2 = 0.78) but not superior to the prototype under commercial operating conditions. Mean absolute error reported for humans was 37 kg; approximately 2.8 times that of the prototype.

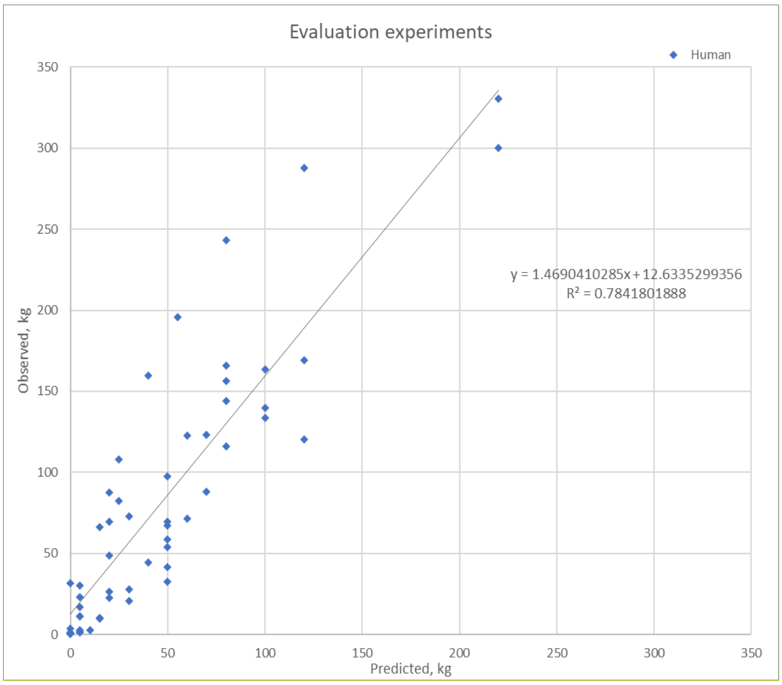
Table 2. Evaluation statistics for estimation of feed remaining for humans and prototype system in Experiment 2 in the commercial feedlot operating environment.

Item	Humans	Prototype system[1]
Mean bias, kg	34.636	11.297
P-value	< 0.001	< 0.001
Linear bias	0.469	0.037
P-value	< 0.001	0.063
r^2, regression of observed on predicted feed remaining	0.784	0.982
RMSPE, kg	55.71	15.89
MSPE, kg^2	3,103.14	252.45
MAE, kg	36.97	12.22
Mean proportional bias	0.55	0.90
Decomposition of MSPE		
Mean bias, %	38.66%	50.55%
Systematic bias, %	16.58%	3.14%
Random bias, %	44.76%	46.30%
Bias at minimum predicted value, kg	12.63	-
Bias at maximum predicted value, kg	115.82	-

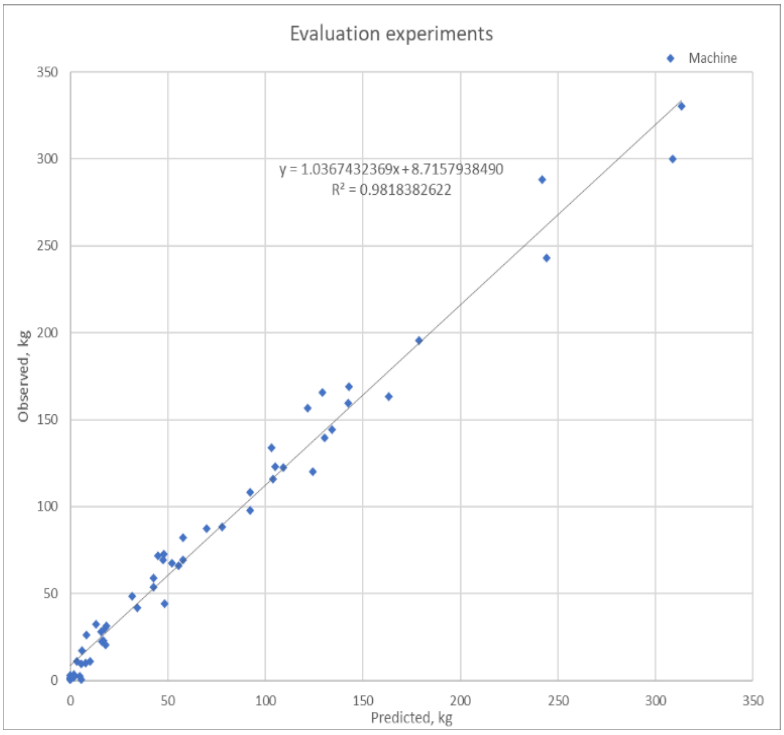
1 Volume of feed remaining was determined from post-processing of lidar point-cloud data.

The total experiment observed on predicted feed remaining for both humans and prototype system are represented graphically below in Figure 3. Visual inspections of Figure 3 reinforce the outcomes achieved through the objective statistical analyses. Specifically, and once again, the prototype's predictions are significantly closer to the line of regression, hence significantly more precise; this is also demonstrated by the r^2 value shown in the provided equations in the figures. The humans' predictions are generally significant under-predictions, and the apparent inconsistencies of these calls is also demonstrated by a lesser r^2 value.

To further demonstrate the benefit of the statistical evaluation of mean and linear bias presented by St-Pierre (2003), plots for residuals on mean-centred predictions are provided in Figure 4. Visual inspection of the prototype system evaluation detailed in Figure 4 further indicate the high level of accuracy across all observed masses, albeit with a minor mean offset; in this case a consistent under prediction of approximately 11 kg across the experimental data. The humans plot in this figure visually demonstrates large numbers of under predictions (based on residuals) for most feed remaining masses, and it can be observed these have a significant linear bias as the feed remaining masses increase, as well as being largely influenced by random predictions.

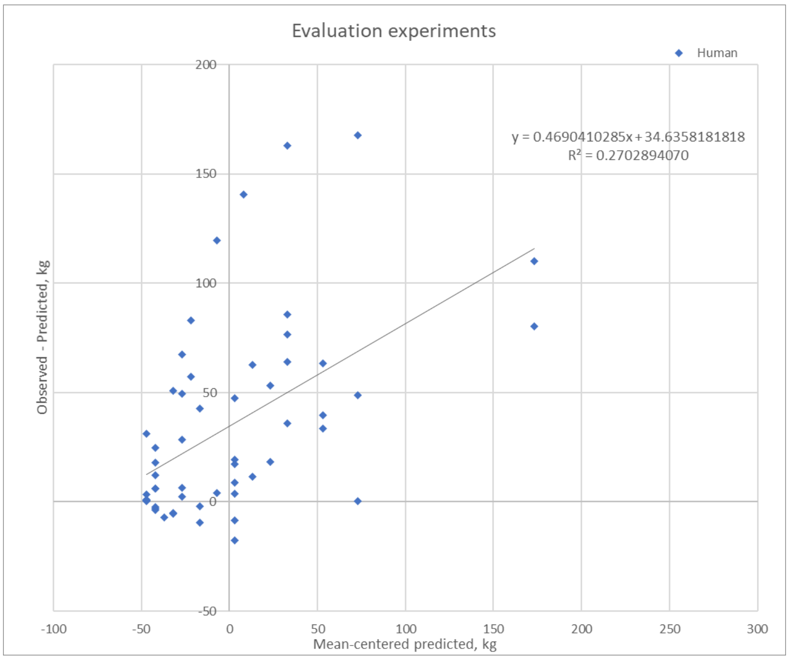


a. Human bunk callers

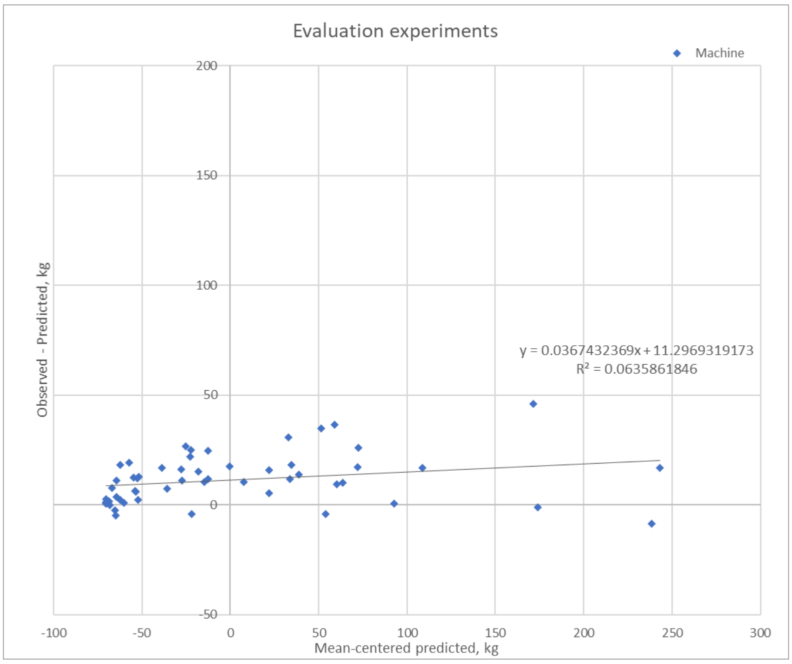


b. Prototype bunk scanner

Figure 3. Observed on predicted feed remaining for (a) humans and (b) prototype system



a. Human bunk callers



b. Prototype bunk scanner

Figure 4: Residuals (observed minus predicted) on mean-centred predicted for (a) humans and (b) prototype system

5 Conclusions

Against the results presented in this report, the prototype bunk calling system provided highly repeatable (precise) and accurate feed remaining determinations. In contrast, the human callers provide significantly less accurate and precise feed remaining predictions across all the experiments, especially at higher masses. Their performances with lesser feed remaining masses are probably acceptable for normal operating requirements.

A statistical methodology has been exercised with a view to assess feed remaining predictions provided by the prototype system and human callers. The methodology has provided very clear and objective support for the prototype system's precision and accuracy. The feedlot experiment results also suggest the significance of feed density knowledge, and especially how it may change after-delivery through a 24-hour cycle. It is believed that this is the major contributing factor for the feedlot experiment's minor underpredictions, though the influence of this effect could be simply mitigated programmatically. Further extended campaigns of measurement are required across diverse feedlot sites to determine the robustness of the prototype versus human observation.

6 Key messages

The prototype bunk scanner demonstrates exciting promise to determine feed remaining in bunks, with performance superior to human operators. We believe this to be a world first application of the aforementioned technology that paves the way to objective automation of bunk management and represents a high-value outcome for the Australian feedlot industry.

With MLA's support, we have delivered a prototype that has demonstrated significant potential benefit to the red meat industry. We suggest that a commercially-viable product should be available in the near term based on the successful outcomes of this project.

7 Bibliography

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