final report

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Feasibility study of BeefSpecs optimisation model to a feedlot (Stage 1)

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Executive Summary

Australian Country Choice (ACC) has a master vision to develop and build on current systems and capabilities in data measurement and management to facilitate in real time cost management across the business including processing and livestock production. A full scope of work consisting of 5 phases has been developed to evaluate, implement and optimise a feedlot induction process across ACC's business. In the current project, a feasibility study was proposed to determine the value of the BeefSpecs feedlot optimisation model to the ACC feedlot production system (Stage 1).

This study has successfully completed an initial ACC feedlot assessment of cattle from induction through to slaughter. Critical inputs into the model include initial weight, P8 fat, frame score (calculated from age and hip height), breed type, ADG, days on feed, dressing precent, and feed type (grass or grain). Specifically, it was identified from an initial ACC feedlot investigation that the company required an initial preliminary evaluation of sorting system(s) that:

1. Sorts individuals at induction into pens that will take a similar DOF to reach the desired ACC set carcass endpoint.
2. Can be made dynamic and be updated with variables such as feed intake, weather data, pen conditions to give a daily update of performance of that pen [e.g. carcass characteristics, profit ($/hd) and incremental carcass cost of gain]. Days on feed can therefore be adjusted in real-time to maximise profit of feeding that pen.
3. Focuses on individuals and calculates the production cost of a carcass at the processing plant.
4. Provides value over the current method of sorting at ACC.
5. Evaluate objective data capture methods at induction (3D Camera, Ultrasound) as methods of turnoff potential (note this is additional to the original scope of the project)

The optimisation results are based on a per pen basis which is more realistic than a per animal optimisation. This analysis is retrospective but the current management strategies provide a base line dataset to analyse current and future management strategies to improve profitability. If a BeefSpecs feedlot optimisation tool was to be implemented into the ACC operation then real-time optimisation processes would need to be applied.

To further develop BeefSpecs as a feedlot induction process, the following stages need to be further developed:

- Implement a P8 fat assessment strategy.
- Real-time market specifications.
- Access P8 fat assessment strategy with a BeefSpecs optimisation before a full implementation.
- Extension of the current 3D camera system to also include European and *Bos indicus* breeds.

In addition, it is proposed that the next steps would be the extension of the current 3D camera system to also include European and *Bos indicus* breeds to cover the entire spectrum of breed combinations present at ACC feedlots. The analysis of this data and the reporting of these results is proposed to be conducted at a later date within the ALMTech program.

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1 Background

Introduction

Australian Country Choice (ACC) has a strategic business imperative to ramp production and move towards seven-day beef production at their Cannon Hill facility. Data measurement and management systems will be critical to the whole of business improvement approach that ACC is implementing. ACC's vision is to develop and build on current systems and capabilities in data measurement and management to facilitate improvement in real time cost management across the business. ACC is currently evaluating current red meat industry data capture, analysis and management systems used across the red meat supply chain in livestock production, feedlots, processing, logistics, wholesaling and or retailing.

In recent years, there have been advancements in modelling techniques both in Australia and the United States to sort feedlot cattle to achieve this goal. One such Australian model – is the BeefSpecs model (Walmsley *et al.* 2014) which is built off growth models from the US Meat Animal Research Centre in Nebraska (Keele *et al.* 1992), with further refinements by the Beef CRC/NSW DPI (Walmsley *et al.* 2010; 2014). This model has been applied to improve carcass compliance in the grazing industry (MLA study B.SBP.00111), and a BeefSpecs fat calculator (http://beefspecs.agriculture.nsw.gov.au/) has been extended to industry. Specifically, the model predicts P8 fat accretion for a set rate of average daily gain (ADG; kg/day) over a defined time period.

Critical inputs into the model include initial weight, P8 fat, frame score (calculated from age and hip height), breed type, ADG, days on feed, dressing precent, and feed type (grass or grain). The BeefSpecs model has several functions in more advanced versions, including the capacity to sort feedlot cattle into carcass outcome groups at feedlot entry, and optimise profitability of pens by looking retrospectively at closeout data (i.e. BeefSpecs Feedlot Optimisation model; Mayer at al. 2013). This project also builds on the original work conducted between NSW DPI and the University of Technology Sydney (MLA study B.BSC.0339) to objectively predict hip height and assess muscle score and P8 fat of Bos taurus cattle using RGDB cameras. As requested an additional task of assessing the estimated live weight on the chain was conducted.

The current project with ACC specifically evaluates data for the potential development of an optimised BeefSpecs system for customised application across the ACC supply chains. Data has been captured from an ACC feedlot for analysis and possible future development of a BeefSpecs optimisation to accommodate other business units within the ACC Company. By using data and information generated in the business, it will provide insights to inform supply decisions that create new business and markets from livestock production through to primary processing.

The purpose was to conduct a simulated BeefSpecs Feedlot Optimisation and report on the observed versus predicted carcase characteristics. The outcome will be a detailed feasibility report of BeefSpecs options with commercial options and recommendations on proposed next stages for full adoption of BeefSpecs across the business (i.e. livestock production to processing).

2 Project Objectives

2.1 Overall objective

The overall objective was to evaluate data measurement and management system options that will be critical to the whole of business improvement approach that ACC is implementing.

Specific objectives of the stage 1 feasibility study included at induction and on exit of 1000 head of cattle:

- Subjectively assess hip height and muscle score,
- Estimate P8 fat using ultrasound technology,
- Collect 3D camera images (i.e. additional work to the scope of the project), and
- Animal data cross-checked with carcase and grading data (i.e. at the processing plant).

3 Methodology

3.1 Animals

A mature cow dataset (n=1856) [see Figures 1 and 2] that included age (months), live weight (kg), hip height (cm), P8 fat (mm) and MS from the NSW DPI low and high muscling herd was used. The data was checked and outliers were removed from the study.

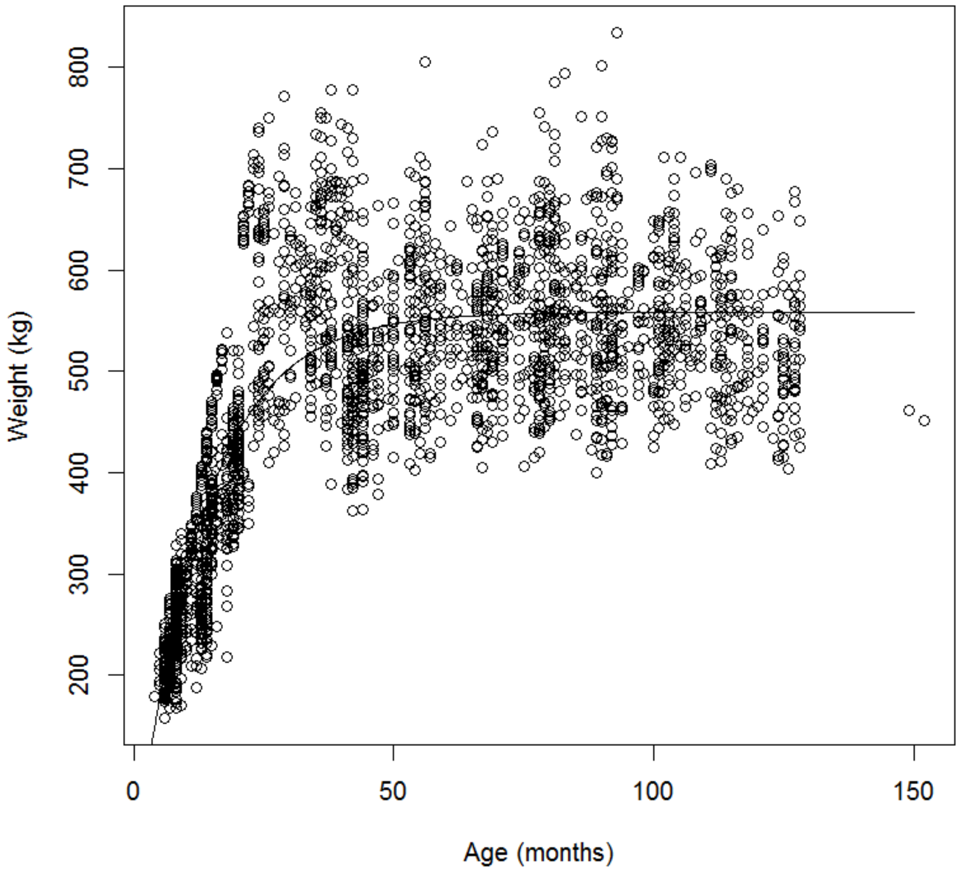

Figure 1. Weight (kg) versus age (months) of the mature cow dataset with line of best fit (solid line) to illustrate the plateau of weight when cows have reached a mature size.

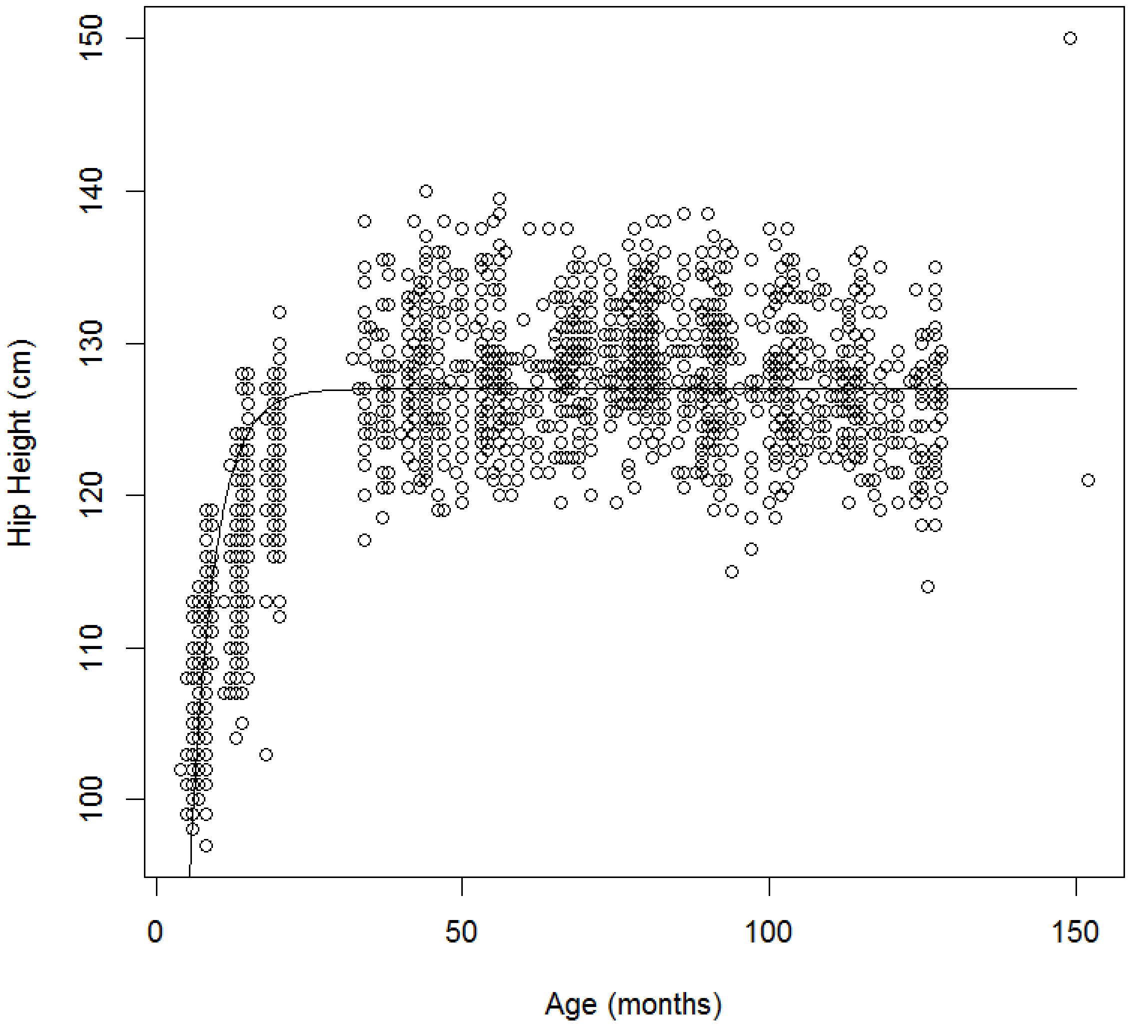

Figure 2. Hip height (cm) versus age (months) of the mature cow dataset with line of best fit (solid line) to illustrate the plateau of hip height when cows have reached a mature size.

3.2 Assessing age

The relationship between permanent incisors and age (Table 1 and Figure 3) were to be used to assess age.

Table 1. Age (months) as determined by the number of permanent incisors

No of permanent incisors	Age (months)
1-2	18 to 30
3-4	24 to 36
5-6	30 to 42
7	36 to 48
8	42 + months

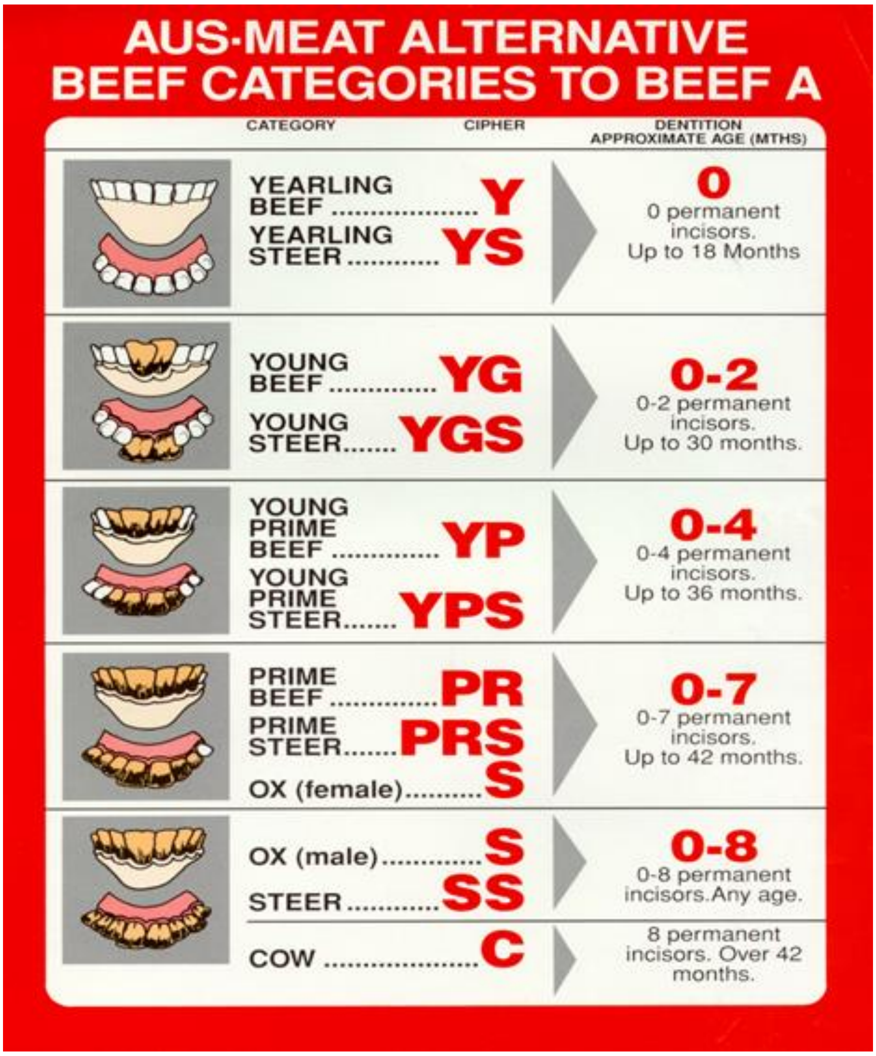

Figure 3. AusMeat beef categories to determine age of cattle

3.3 Calculations

Frame scores were calculated using the frame score tables (NSW Department of Primary Industries 2017) converted to calculate a real continuous variable rather than an integer. The real continuous frame score values were used in the model development. Cows > 36 months of age were used to determine the average mature hip height. All predicted frame scores from the heifer model were rounded to an integer.

3.4 Models

Heifer model A mutli-linear model was fitted to the cow data frame score (age < 36 months) using the lm routine (Chambers, 1992) in R (R Development Core Team, 2013). Covariates evaluated in the model were hip height (cm), live weight (kg), muscle score, and P8 fat. The assumptions of normality were checked and a square root transformation was applied to the model. Non-significant (P > 0.05) effects were removed from the model. A graph of the residuals is reported.

Steer model A linear model was fitted to steer hip height (cm) versus heifer hip height (cm) from the hip height tables (NSW Department of Primary Industries 2017) for frame score relationships (1 to 11) to develop models to adjust the heifer hip height using the lm routine (Chambers, 1992) in R (R Development Core Team, 2013). The steps to calculate steer frame score were as follows: (1) frame score is calculated from the heifer model; (2) hip height for steers is adjusted from the linear models for each individual frame score and (3) then recalculated using the heifer model.

4 Results

4.1 Data

Summary of the cow data to determine mature frame score is shown in Table 2 where age of the cows varied from 37 to 152 months. Summary of the data to develop the model is shown in Table 3 where age varied from 4 to 21 months.

Table 2. Summary of high and low muscling herd cow dataset for age (mth), live weight (LW), frame Score (FS), hip height (cm), P8 fat (mm) and muscle score (MS) on mature cows (age > 36 months) to determine the mature frame score

	n	Mean	min	max	SD
Age (mth)	1340	78.71	37	152	25.55
LW (kg)	1338	541.39	362	834	71.99
FS	1339	4.05	1	7	0.83
Hip Height (cm)	1339	127.79	114	150	4.04
P8 fat (mm)	1339	9.13	1	84	10.36
MS	1340	7.20	1	14	3.27

Table 3. Summary of high and low muscling herd cow model development dataset for age (months), live weight (LW), frame Score (FS), hip height, P8 fat and muscle score (MS) on cows (age <= 36 months), where FS was calculated as the average FS on mature cows (age > 36 months) which has been repeated for weaning and yearling cow data (age <= 36 months) for individual animals

	n	mean	Min	max	SD
Age (mth)	516	11.79	4	21	4.74
LW (kg)	516	291.52	158	520	74.35
FS	516	4.21	2.25	6.35	0.77
Hip Height (cm)	516	113.91	97	132	7.46
P8 fat (mm)	516	5.22	0	23	3.37
MS	516	7.34	1	15	3.03

Independent datasets to evaluate the heifer and steer predictions were available from slaughter studies on low and high muscling heifers and steers conducted by NSW DPI with funding from MLA (MLA funded projects: B.BSC.0339, B.SBP.0108 and B.SBP.0111). A summary of the data is shown in Tables 4 and 5.

Table 4. Summary of NSW DPI low and high muscling Angus heifers for grass and feedlot finished, and serial slaughter datasets (MLA funded projects: B.BSC.0339, B.SBP.0108 and B.SBP.0111).

	n	Mean	Min	Max	SD
Age (mth)	172	12.78	7	21	3.87
Development data					
LW (kg)	172	315.25	164	640	91.53
FS	172	4.41	2	7	1.02
Hip Height (cm)	172	116.28	98.50	133.50	6.77
P8 fat (mm)	172	6.30	1	20	3.85
MS	172	7.16	1	12	2.07

Table 5. Summary of NSW DPI low and high muscling Angus steers for grass and feedlot finished, and serial slaughter datasets (MLA funded projects: B.BSC.0339, B.SBP.0108 and B.SBP.0111),

	n	Mean	min	Max	SD
Age (mth)	709	14.17	6	23	4.08
Validation data					
LW (kg)	709	369.48	165	740	109.03
FS	709	3.91	1	7	1.08
Hip Height (cm)	709	121.15	97	144	7.77
P8 fat (mm)	709	4.87	1	22	3.80
MS	709	7.97	2	13	2.80

4.1.1 Heifer model development

The covariates hip height (HH; cm), live weight (LW; kg), muscle score (MS) and P8 fat (mm) were all included in the model. P8 fat was not significant ($P < 0.05$) and was removed from the model. The coefficients of the model developed are shown in Table 6 and the analysis of variance is shown in Table 7. A square root transformation was required so that the experimental errors are independently and normally distributed on the transformed scale. Residuals of the model are shown in Figure 4. Note: model requires the frame score to be squared to back transform frame score.

Table 6. Coefficients of the multi-linear model developed for the frame score (FS) relationship between hip height (HH), live weight (LW), and muscle score (MS) of the cow dataset (age <= 36 months); standard error (Std.Error) for each coefficient and the residual standard error (RSE) and adjusted (Adj) R-squared for the full model and the degrees of freedom (DF).

Term	Estimate	Std.Error	t value	Pr(>|t|)	
(Intercept)	0.4370	0.1916	2.28	0.023	P < 0.05
HH	0.0176	0.0021	8.47	2.72E-16	P < 0.001
LW	-0.0009	0.0002	-4.45	1.05E-05	P < 0.001
MS	-0.0174	0.0025	-6.98	9.10E-12	P < 0.001
RSE	0.16				
Adj R-squared	0.30	512	DF		

Table 7. Analysis of variance of the multi linear model fitted to the cow dataset (age <= 36 months) for the frame score (FS) relationship of the cow data set between hip height (HH), live weight (LW), and muscle score (MS); residuals, degrees of freedom (DF), sums of square (Sum Sq), and mean squared (Mean Sq).

	DF	Sum Sq	Mean Sq	F value	Pr(>F)	
HH	1	2.83	2.83	113.56	2.20E-16	P < 0.001
LW	1	1.49	1.49	59.80	5.61E-14	P < 0.001
MS	1	1.22	1.22	48.74	9.10E-12	P < 0.001
Residuals	512	12.77	0.025			

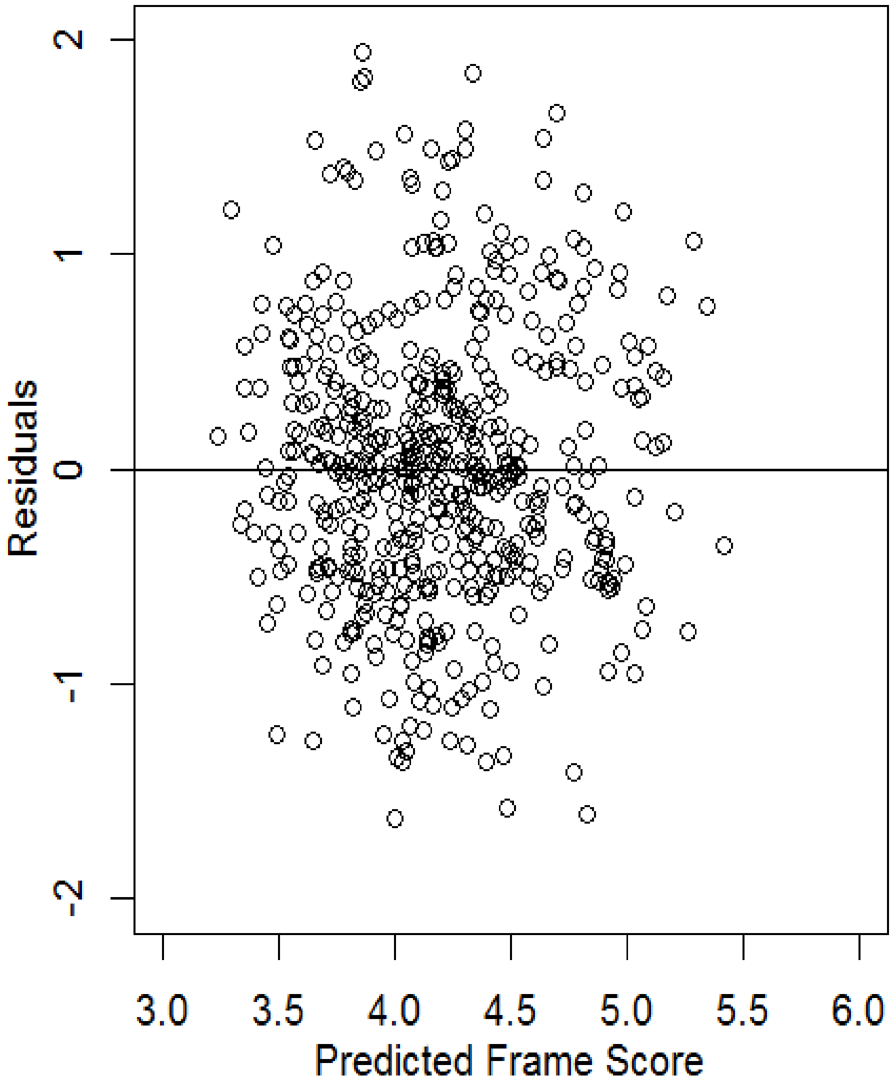

Figure 4. The residuals of the frame score heifer model developed from the cow data (age <= 36 months).

4.1.2 Development of models to adjust steer hip height

The linear models developed to adjust steer hip heights are shown in Figure 5 and the coefficients of the linear models are reported in Table 8.

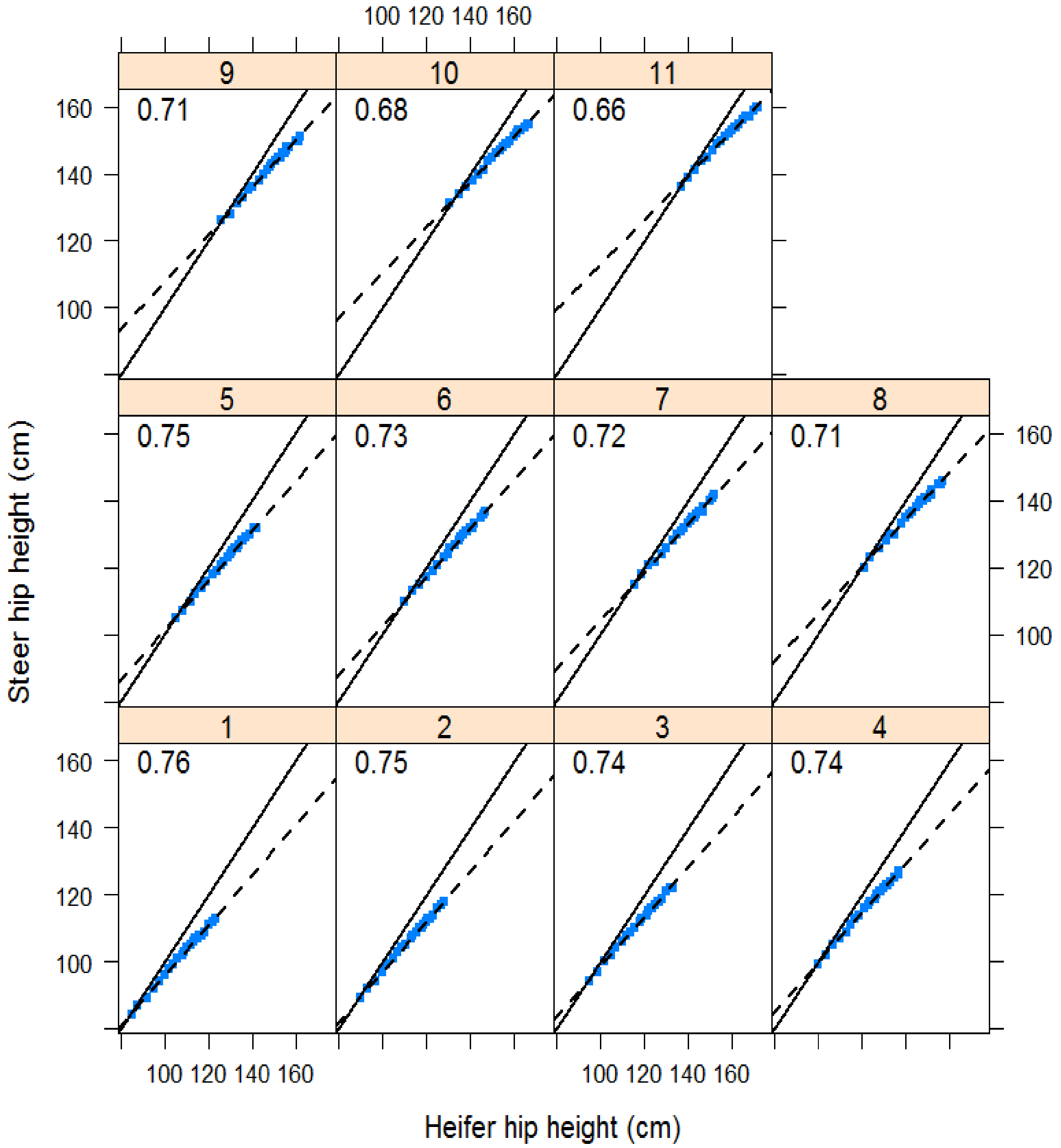

Figure 5. Relationship between steer and heifer hip height (HH; cm) based off a set of HH tables (NSW Department of Primary Industries. 2017) for both steers and heifers at frame scores from 1 to 11; the blue diamonds are actual values from the tables, dashed lined is the linear line of best fit, the solid line is a 1:1 relationship and values displayed are the slope coefficients of the models developed for each frame score.

Table 8. Coefficients of linear equations developed for the relationship between steer and heifer hip heights (HH) and the residual standard error (RSE), adjusted (Adj) R-squared, and standard error (Std.Error) for each coefficient for each frame score (FS).

Term	FS	Estimate	Std.Error	FS	Estimate	Std.Error
(Intercept)	1	20.31	0.93	7	32.41	1.25
HH		0.76	0.01		0.72	0.01
RSE		0.44			0.44	
Adj R-squared		0.997			0.997	
(Intercept)	2	22.19	0.85	8	35.31	1.43
HH		0.75	0.01		0.71	0.01
RSE		0.39			0.48	
Adj R-squared		0.998			0.996	
(Intercept)	3	23.99	0.98	9	37.26	1.39
HH		0.74	0.01		0.71	0.01
RSE		0.42			0.45	
Adj R-squared		0.997			0.996	
(Intercept)	4	25.65	1.18	10	42.26	1.45
HH		0.74	0.01		0.68	0.01
RSE		0.48			1.00	
Adj R-squared		0.996			0.996	
(Intercept)	5	26.71	0.93	11	46.26	2.00
HH		0.75	0.01		0.66	0.01
RSE		0.36			0.60	
Adj R-squared		0.998			0.992	
(Intercept)	6	30.05	0.94			
HH		0.73	0.01			
RSE		0.35				
Adj R-squared		0.998				

4.1.3 Frame score versus hip height

The heifer model (Table 9) was rearranged with HH as the dependent variable. Hip height was then calculate with live weight at 250, 350, and 450 kg, frame score at 2 to 7 and muscle score fixed at 8. The heifer relationship between frame score and hip height is illustrated in Figure 6. To develop the steer relationship the HH was initially calculated with the rearranged equation and then the linear equations for the respective frame scores were adjusted using the equations in Table 8. The steer relationship between frame score and hip height is illustrated in Figure 7.

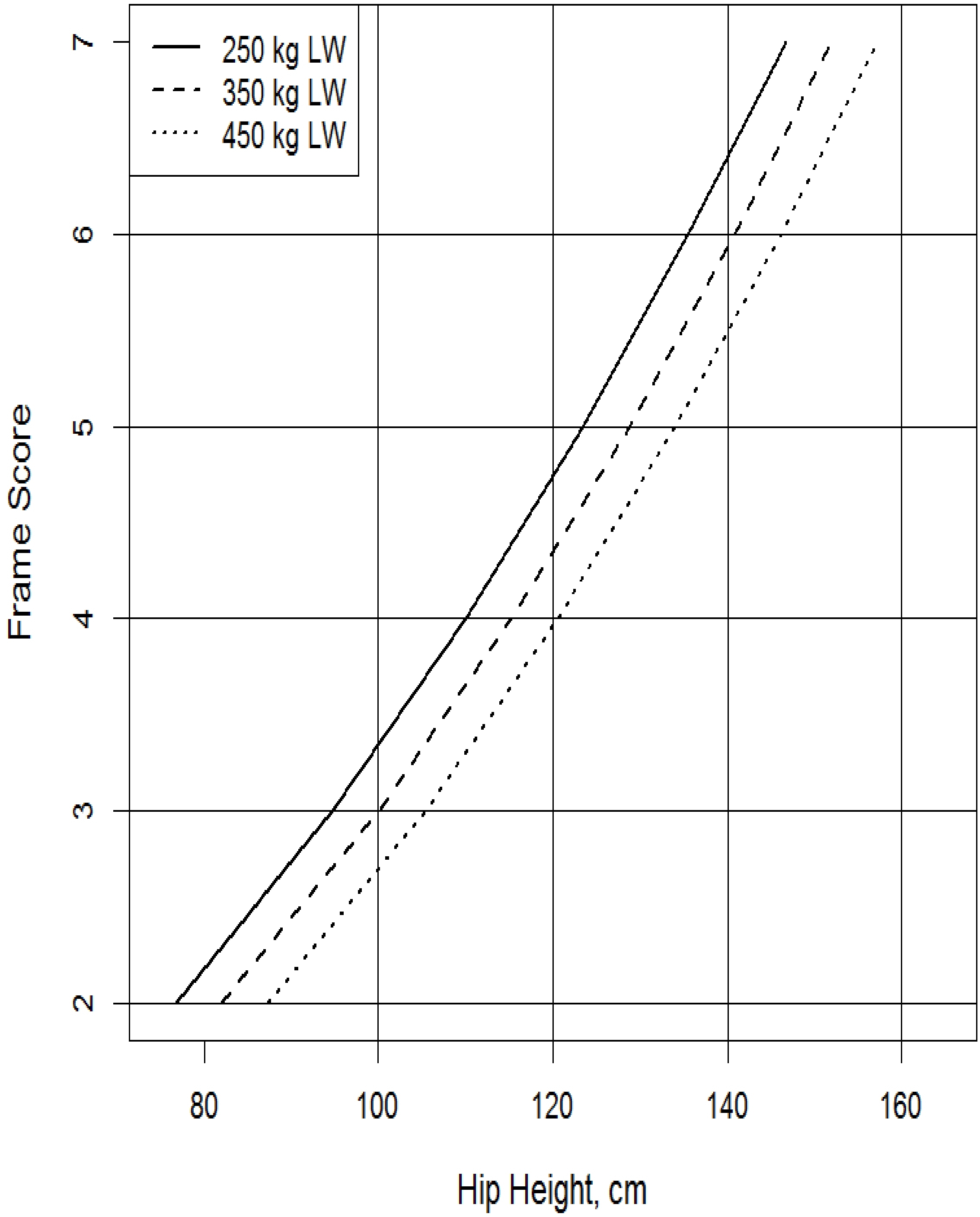

Figure 6. Heifer relationship of the multi-linear frame score (FS) model between frame score and hip height (cm) for live weight (LW) at 250, 350, 450 kg, approximate pseudo of age 9, 13, 17 months respectively with muscle score fixed at 8.

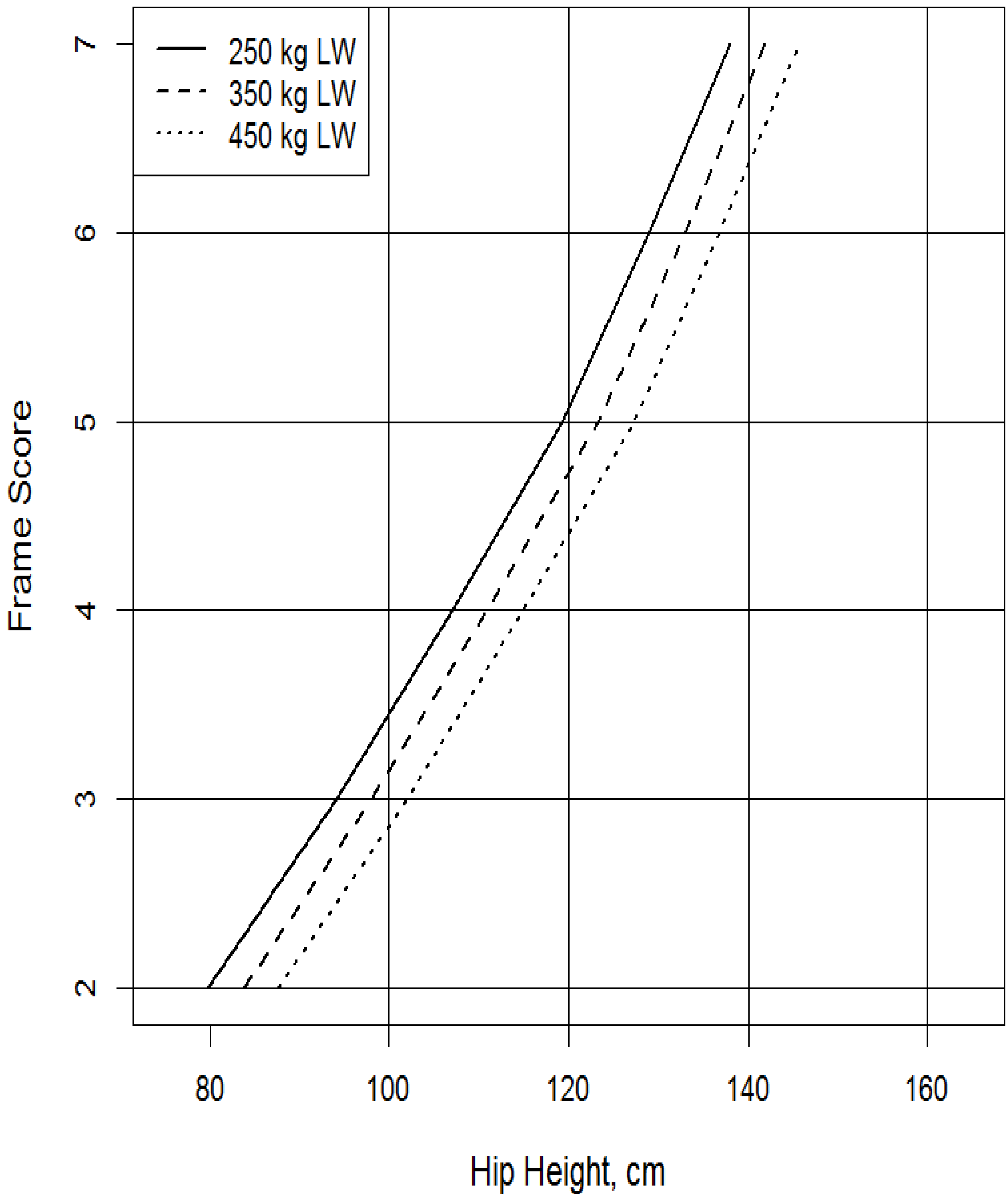

Figure 7. Steer relationship of the FS model and hip height (HH, cm) adjusted using the linear HH equations at different frames scores between frame score and hip height (cm) for live weight (LW) at 250, 350, 450 kg, approximate pseudo of age 9, 13, 17 months respectively with muscle score fixed at 8.

4.1.4 Model evaluation

The mean bias between the calculated frame score and predicted frame score (rounded to an integer) was over predicted for heifers and under predicted for steers (Table 9). There were no significant differences ($P < 0.05$) in the mean bias between calculated and predicted values for heifers and steers (Table 9). There were no significant differences ($P < 0.05$) when testing for the slope (Ho: slope=1) for steers and heifers (Table A9.8). Heifers had the lowest square root mean square error of prediction (RMSEP) (Table 9). The decomposition of the MSEP revealed that most of the error contained in the predictions for heifers and steers was of a random nature. There was a small amount of bias and very little slope error (Table 9).

Table 9. Model evaluation of frame score for heifers and steers using the NSW DPI low and high muscling data reported in Tables 4 and 5.

Item	Heifers	Steers
n	172	709
Mean calculated	4.41	3.91
Mean predicted	4.22	4.05
Mean bias	0.19	-0.14
b coefficient	0.97	0.90
P[1]	< 0.05	< 0.05
P[2]	-0.03	-0.11
MSEP[3]	0.86	0.99
Root-MSEP	0.93	1.0
Bias, %	4.02	2.09
Slope, %	0.02	0.27
Random, %	96.0	97.6
Additional stats		
R	0.45	0.41

[1]Paired t-test for the mean bias ($P < 0.05$)
[2]Student's t-test for the slope (H_o: slope=1) at ($P < 0.01$)
[3]MSEP = mean square prediction error, Bias = MSEP decomposed into error due to overall bias of prediction; Slope = MSEP decomposed into error due to deviation of the regression slope from unity, Random = MSEP decomposed into error due to the random variation

A plot of the calculated versus the predicted frame score with a 1:1 (y = x) line and a plot of the residuals (calculated – predictions) with a horizontal line (y = 0) across heifers and steers has provided additional detail on the accuracy of predicting frame score (Figs. 7 and 8). Heifer data illustrates that the data follow the 1:1 line and the residuals demonstrate an error of ±2 frame scores. The steer data also followed a 1:1 relationship with a greater error (±2.5 frame scores) than the heifers.

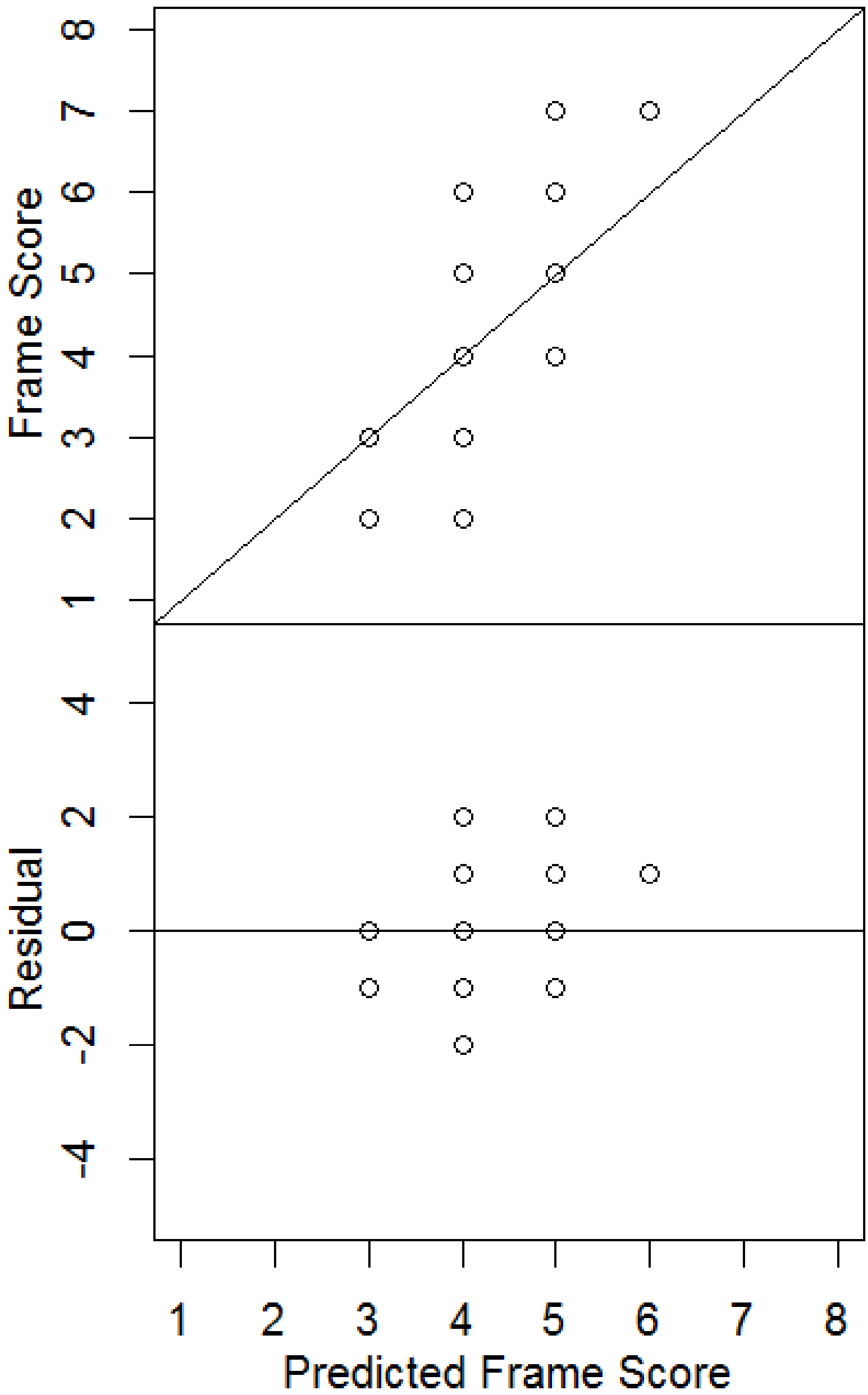

Figure 8. Accuracy of predicting frame score (integer) versus calculated frame score based on age and hip height (HH) from the heifer HH tables with a linear 1:1 line and the residuals using the NSW DPI low and high muscling data reported in Table 3. (Duplicates under data points).

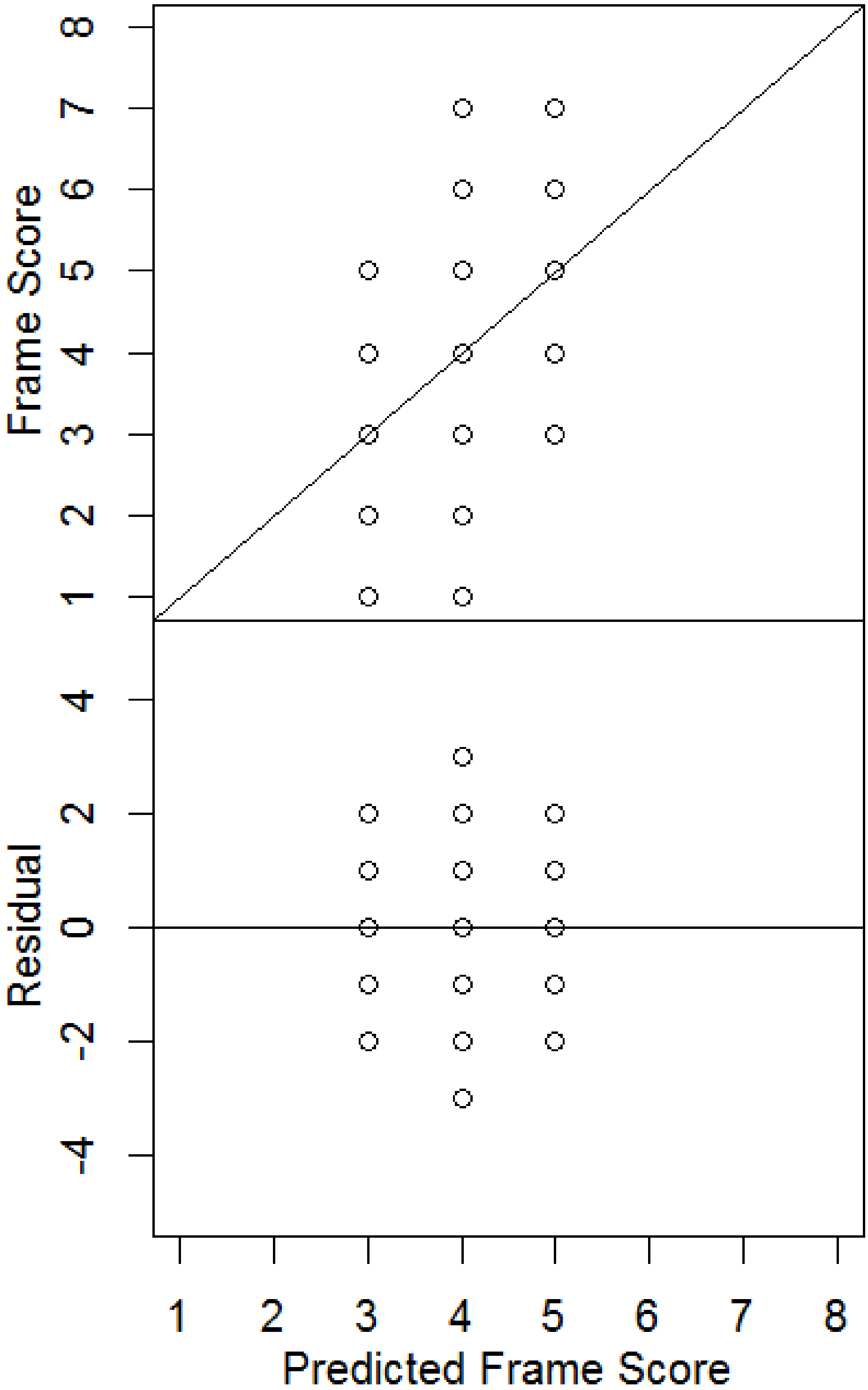

Figure 9. Accuracy of predicting frame score (integer) versus calculated frame score based on age and hip height (HH) from the steer HH tables with a linear 1:1 line and the residuals using the NSW DPI low and high muscling data reported in Table A9.4. (duplicates under data points).

5 Discussion

This study has successfully completed an ACC feedlot assessment of cattle from induction through to slaughter. Critical inputs into the model include initial weight, P8 fat, frame score (calculated from age and hip height), breed type, ADG, days on feed, dressing precent, and feed type (grass or grain). Specifically, it was identified from an initial ACC feedlot investigation that the company required an initial preliminary evaluation of sorting system(s) that:

- Sorts individuals at induction into pens that will take a similar DOF to reach the desired ACC set carcass endpoint.
- Can be made dynamic and be updated with variables such as feed intake, weather data, pen conditions to give a daily update of performance of that pen [e.g. carcass characteristics, profit ($/hd) and incremental carcass cost of gain]. Days on feed can therefore be adjusted in real-time to maximise profit of feeding that pen.
- Focuses on individuals and calculates the production cost of a carcass at the processing plant.
- Provides value over the current method of sorting at ACC.
- Evaluate objective data capture methods at induction (3D Camera, ultrasound) as methods of turnoff potential (note this is additional to the original scope of the project).

The data collected (e.g., live weights, breed content, P8 fat assessments, carcass traits) to conduct a BeefSpecs Feedlot Optimisation has demonstrated the process to:

- Assess market compliance rates.
- Actual non-compliance for HSCW and P8 fat (mm).
- Profitability reporting.

The optimisation results are based on a per pen basis which is more realistic than a per animal optimisation. This analysis is retrospective but the current management strategies provide a base line dataset to analyse current and future management strategies to improve profitability. If a BeefSpecs feedlot optimisation tool was to be implemented into the ACC operation then a real-time optimisation would be applied.

The BeefSpecs model has several functions in more advanced versions, including the capacity to sort feedlot cattle into carcass outcome groups at feedlot entry, and optimise profitability of pens by looking retrospectively at closeout data (i.e. BeefSpecs Feedlot Optimisation model; Mayer at al. 2013). This project builds on the original work conducted between NSW DPI and the University of Technology Sydney (MLA study B.BSC.0339) to objectively predict hip height and assess muscle score and P8 fat of Bos taurus cattle using RGDB cameras. The next steps is propose to be the extension of the current 3D camera system to also include European and Bos indicus breeds to cover the entire spectrum of breed combinations present at ACC feedlots. The analysis of this data and the reporting of these results is proposed to be conducted at a later date within the ALMTech program.

6 Conclusions/Recommendations

6.1 Conclusions

ACC has a master vision to develop and build on current systems and capabilities in data measurement and management to facilitate in real time cost management across the business including processing and livestock production. A full scope of work consisting of 5 phases has been developed to evaluate, implement and optimise a feedlot induction process across ACC's business. In the current project, a feasibility study (i.e. Stage 1) was proposed to determine the value of the BeefSpecs feedlot optimisation model to the ACC feedlot production system (Stage 1).

This study has successfully completed an ACC feedlot assessment of cattle from induction through to slaughter.

6.2 Recommendations / Next Steps

To further develop BeefSpecs as a feedlot induction system, the following stages need to be further developed:

- Implement a P8 fat assessment strategy.
- Real-time market specifications.
- Access P8 fat assessment strategy with a BeefSpecs optimisation before a full implementation.
- Extension of the current 3D camera system to also include European and *Bos indicus* breeds.

In addition, it is proposed that the next steps would be the extension of the current 3D camera system to also include European and *Bos indicus* breeds to cover the entire spectrum of breed combinations present at ACC feedlots. The analysis of this data and the reporting of these results is proposed to be conducted at a later date within the ALMTech program.

Furthermore, there is a need to conduct assessment of P8 fat (mm) on-farm, at induction and feedlot exit. The options being considered to further develop P8 fat prediction / measurement include:

- Can be achieved immediately by purchasing an ultrasound scanner worth $30,000 and training at least two assessors.
- Can be achieved by hiring a consultant to come on site and assess cattle at $8 per head.
- Can be achieved by installing a 3D camera system before the crush.
    - Steps required include 'proof of concept' of 3D camera system on different breed contents.
    - Validation studies against ultrasound scanned P8 fat.
    - Estimated cost of a system $800 plus on site development costs (est. at $500) and ongoing maintenance cost yet to be determined. Research yet to be fully completed (est. maintenance cost of $200/year).

7 Key Messages

7.1 Commercial practicality of using BeefSpecs

The recommendation of implementing assessment of P8 fat (mm) at induction and exit of the feedlot is simple and easy to do. It is a 'do now' option by purchasing ultrasound equipment to assess P8 fat. A simple computerized graphical grid could then be developed where the P8 fat and HSCW could be entered based on the customer's grid. This is simple and easy to develop. The input of dressing percentage would also need to be entered and then as cattle either enter or exit the feedlot a quick and simple snap shot could be displayed. This in itself would provide the team at ACC with an educational tool of managing their cattle to improve overall compliance. Based on the information gathered from the graphical representation of 'meeting market specifications' a management decision could then be made to either send cattle immediately off to be slaughtered or held back so that they do 'meet the specifications'. As shown in the report a substantial cost saving can be incurred through making such a management decision. And in addition to this there are potential savings through an optimised solution.

A simple implementation of a system to assess fat incorporated with a simple graphical display for entry and exit assessments has the potential to substantially improve the overall profitability of the feedlot operation. The implementation of optimising the BeefSpecs Feedlot Optimisation tool could then be looked at further. But the simple approach taken may prove to educate buyers of cattle along with feedlot managers with the required information to make good management decisions that increase 'market compliance' rates to an acceptable level with a substantial increase in profitability that do not require a BeefSpecs Feedlot Optimisation.

7.2 Further development of BeefSpecs

An initial step to demonstrate this concept would be:

1. Software developed, implemented and tested to interact with feedlot software to display the grid.
2. Hire an experienced assessor for 1 week to assess cattle and:
    a. Send induction cattle within specifications off to slaughter straight away.
        i. Note: slaughtered MSA data would need to be evaluated to see if additional losses associated with meat quality and fat colour make this option unviable; and
        ii. Note: current data indicate a substantial saving can be made from not feeding cattle that have already met 'market specifications'
    b. Hold exit cattle back if they fail to meet market P8 fat or HSCW specifications. A decision here needs to be made in regards to where the heaviest discounts apply. The results demonstrated that feeding them longer may incur penalties for being out of specifications with P8 fat but getting them in the HSCW range reduces the overall associated loss.

8 Bibliography

Bibby J, Toutenburg H (1977) 'Prediction and improved estimation in linear models.' (John Wiley & Sons Ltd: Akademie - Verlag Berlin, German Democratic Republic)

Brethour JR (1992) The repeatability and accuracy of ultrasound in measuring backfat of cattle. *Journal of Animal Science* **70**, 1039-1044.

Keele JW, Williams CB, Bennett GL (1992) A computer model to predict the effects of level of nutrition on composition of empty body gain in beef cattle: I. Theory and development. *Journal of Animal Science* **70**, 841-857.

Mayer DG, Walmsley BJ, McPhee MJ, Oddy VH, Wilkins JF, Kinghorn BP, Dobos RC and McKiernan WA (2013). Integrating stochasticity into the objective function avoids Monte Carlo computation in the optimisation of beef feedlots *Computers and Electronics in Agriculture* **91:** 30-34

Mitchell PL (1997) Misuse of regression for empirical validation of models. *Agricultural Systems* **54**, 313-326.

McKiernan WA (2007) Muscle scoring beef cattle. Primefacts. NSW Department of Primary Industries, Orange, NSW, Australia. 328: 5.

McPhee MJ, Walmsley BJ, Mayer DG, Oddy VH (2014) BeefSpecs fat calculator to assist decision making to increase compliance rates with beef carcass specifications: evaluation of inputs and outputs. *Animal Production Science* **54**, 2011-2017.

McPhee MJ, Walmsley BJ, Skinner B, Littler B, Siddell JP, Caf, LM, Wilkins JF, Oddy VH, and Alempijevic A. (2017) Live animal assessments of rump fat and muscle score in Angus cows and steers using 3-dimensional imaging. *Journal of Animal Science* **95,** 1847–1857.

McPhee MJ, Walmsley BJ, and Alempijvic A (2016) Development of a customised system to sort feedlot cattle into optimal economic endpoints for Australian Country Choice feedlots. Building a value chain for ACC forum. Roma Qld, 6th to 7th January 2016. pp. 1-6

McPhee MJ, Oltjen JW, Fadel JG, Perry D, Sainz RD (2008) Development and evaluation of empirical equations to interconvert between twelfth-rib fat and kidney, pelvic, and heart fat respective fat weights and to predict initial conditions of fat deposition models for beef cattle. *Journal of Animal Science* **86**, 1984-1995.

Neter J, Kutner MH, Nachsheim CJ, Wasserman W (1996) 'Applied Linear Statistical Models.' (McGraw-Hill: Boston)

NSW Department of Primary Industries (2017) Frame scoring of beef cattle. Accessed March 2017. http://www.dpi.nsw.gov.au/animals-and-livestock/beef-cattle/appraisal/publications/frame-scoring

Price KV (1999) An introduction to differential evolution. In 'New Ideas in Optimization'. : (Eds D Corne, M Dorigo, F Glover) pp. 79–108 (McGraw-Hill, London)

R Development Core Team (2014) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org. Version 3.1.1 downloaded on 10th July 2014

Upton W, Donoghue K, Graser H, Johnston D (1999) Ultrasound proficiency testing. In 'Association for the Advancement of Animal Breeding and Genetics'. Volume 13 pp. 341-344.

Storn R, Price K (1997) Differential evolution – A simple and efficient heuristic for global optimization over continuous spaces. *Journal of Global Optimization* **11**, 341–359.

Tedeschi LO (2006) Assessment of the adequacy of mathematical models. *Agricultural Systems* **89**, 225-247.

Walmsley BJ, Wolcott ML, McPhee MJ (2010) Modeling the relationship between scanned rump and 12th-rib fat in young temperate and tropical bovines: Model development and evaluation. *Journal of Animal Science* **88**, 1848-1859.

Walmsley BJ, McPhee MJ, Oddy VH (2014) Development of the BeefSpecs fat calculator to assist decision making to increase compliance rates with beef carcass specifications. *Animal Production Science* **54**, 2003-2010.

Wolcott ML, Thompson JM, Perry D (2001) The prediction of retail beef yield from real time ultrasound measurements on live animals at three stages through growout and finishing. *Australian Journal of Experimental Agriculture* **41**, 1005-1011.