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Calibration of a remote early disease identification system for Australian Feedlots

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Abstract

Accurately identifying bovine respiratory disease is challenging in feedlots, and the objective of this project is to evaluate existing data from two Australian feedlots (MLA project B.FLT.0242) to determine associations between behavioural parameters and health outcomes. Data from the previous trials were used to conduct several analyses to better describe relationships of behavioural and health outcomes. The first portion of the project illustrated significant relationships between consolidation and pleurisy scores and carcass outcomes. The next sections of the project worked to illustrate specific relationships between individual calf behaviour and group (cohort) behaviours and health outcomes. Finally this information was combined to evaluate specific algorithms which will be further evaluated in trials in 2020. The results of this work illustrate that behavioural data is associated with health outcomes and using these data appropriately can enhance respiratory disease diagnosis.

Executive summary

The objective of this project was to evaluate existing data from two Australian feedlots (MLA project B.FLT.0242) to determine potential associations between behavioural outcomes, pleurisy/consolidation scores, and carcass outcomes. The initial statistical analysis compared carcass outcomes of interest to lung consolidation scores, pleurisy scores, and a combined lung / pleurisy score. This analysis demonstrated a significant correlation between consolidation and pleurisy scores and carcass outcomes. The relationship is meaningful as increased (more severe) lung scores resulted in decreased performance. Cattle could be partitioned using lung data and management history into three distinct groups: known healthy (never treated, minimal lung scores), known diseased (treated, died, or lung / pleurisy score of 3 or NS), or uncertain outcomes.

The second objective was to evaluate existing data to describe individual animal differences in activity and feeding patterns associated with wellness status (healthy or sick) as defined by clinical and pulmonary metrics. A data subset was created including only animals with known behavioural data and health outcomes. Data were imported into a statistical software and multivariable models evaluated potential associations between behavioural variables and outcomes of interest. Results illustrated high variability in key behavioural variables including activity parameters (distance travelled and average speed), proximity to areas of interest (time at feed and water), and social indices (average number of calves within 3 meters and time with zero calves within three meters). Further analysis revealed several key factors associated with behavioural outcomes including days on feed, time of day, breed, and wellness status. Key findings included: differentiation in activity between sick and healthy cattle dependent on the time of day, sick cattle spending more time in the water and feeding zones early in the feeding phase (<6 DOF), sick cattle spending more time at the water zone in the overnight hours, sick cattle spending more time in groups early in the feeding phase, then more isolation after the first week on feed. These findings can be used to more accurately describe behaviour in cattle suffering from BRD.

The third objective was to describe group (pen) differences in activity and feeding patterns associated with wellness status as defined by clinical and pulmonary metrics. These analyses revealed daily variability among the behavioural variables and associations among behavioural and health outcomes. Key findings included: wider variability in activity behaviour on days with higher BRD treatment risk, negative associations between activity and the relative risk of BRD treatments in the calf group, decreased time in feed and water when calf group BRD risk was higher, and changes in the social pen behaviour over time. These findings illustrate the importance of calf group level behaviour and results may be useful for cattle managers when evaluating current pen status.

The fourth objective was to select and optimize REDI algorithms for the Australian cattle production system and dynamic platform to customize the sensitivity and specificity based on characteristics of calves in Australian systems. Several new algorithms were created with a range in diagnostic sensitivity and specificity. Virtual trials were performed to test diagnostic performance of ten algorithms and ten algorithm combinations. Algorithms were evaluated based on training data from calves considered healthy or sick (based on pulmonary lesions at slaughter), and then final evaluation of diagnostic accuracy was performed by applying the algorithms to all cattle in the previous trial. Several new algorithms performed equivalent to previous trials, with some offering improvements by identifying approximately the same number of sick calves as previous algorithms, but with fewer overall disease calls. Increases in algorithm sensitivity were evaluated; however, increasing the sensitivity resulted in a greater total number of disease calls. One challenge in determining true diagnostic accuracy using pulmonary lesions at slaughter as the "gold" standard is the lack of knowing when diseased calves were ill during the feeding phase (or prior to feedlot arrival). Identifying calves and confirming illness at the time of disease can greatly enhance the

overall diagnostic ability of the algorithms. Algorithm performance varied in negative and positive predictive value across disease prevalence; therefore, further adjustments may be beneficial to vary the algorithm utilized to determine illness based on expected changes in true population level disease state across the feeding phase. Overall the algorithms offer an option customized for Australian cattle feeding. Further improvements can be made with a more accurate depiction of the specific timing of the disease process.

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1 Background

1.1 Diagnosis of bovine respiratory disease (BRD)

Diagnosis of bovine respiratory disease (BRD) is a major challenge in the beef industry and BRD identification is commonly based on subjective assessments with relatively poor accuracy. The remote early disease identification (REDI) system provides objective continuous behavioural monitoring and applies classification engines to determine changes in wellness status. The REDI technology has been tested in feedyards in the United States, Canada, and Australia. The Australian trials generated a novel dataset containing individual animal behavioural data, disease occurrences, and magnitude of lung lesions at harvest. We propose using a series of virtual trials to improve our understanding of BRD and customize the existing algorithms for Australia. The virtual trials use this novel, existing data analysed in a variety of manners to answer key questions regarding the relationship between specific cattle behaviours and BRD, as well as animal welfare related outcomes. The REDI algorithms were generated for U.S. cattle and these can be calibrated and optimized for the greater accuracy of detecting BRD in the Australian environment. Results would include an improved fundamental understanding of behaviours associated with BRD and animal welfare offering value to Australian production systems using conventional diagnostic methods as well as identifying areas to prioritize when evaluating new disease detection technologies.

1.2 Potential benefits to Australian grainfed beef producers

Misclassification of diseased cattle are relatively common in feedlot industries and the resulting cases cause long term health consequences or unnecessary therapy. The REDI systems provides an opportunity to improve several areas of primary concern to Australian grainfed beef producers including: judicious use of antimicrobials, animal welfare, and efficient labour allocation. The novel dataset generated from previous Australian cattle trials will allow for further characterization of group and individual animal changes related to BRD status, and because data generated in Australia is used for the calibration work the results will be directly applicable to the Australian grainfed producer. Further understanding of behaviour changes facilitates development of thresholds for feeding, water, and activity within a pen that could impact animal welfare metrics. The BRD classifying algorithms used in the Australian trials were originally optimized for the United States cattle production system, and further research will determine the optimal settings for detecting individual diseased animals in an Australian production system to improve accuracy and timing of BRD diagnosis.

2 Project objectives

2.1 Purpose and Description

Diagnosis of bovine respiratory disease (BRD) is a major challenge in the beef industry and BRD identification is commonly based on subjective assessments with relatively poor accuracy. The remote early disease identification (REDI) system provides objective continuous behavioural monitoring and applies classification engines to determine changes in wellness status. The REDI technology has been tested in feedyards in the United States, Canada, and Australia. The Australian trials (**B.FLT.0242 – Evaluation of the REDI system to detect bovine respiratory disease**) generated a novel dataset containing individual animal behavioural data, disease occurrences, and magnitude of lung lesions at harvest. Two trials were conducted at commercial feedlots in New South Wales, and whilst REDI successfully maintained animal health versus conventional pen riding, did not yield a positive value proposition in terms of carcase weight gain or value. Effects on antimicrobial use varied between feedlots, and further research is required to improve the accuracy of the system to diagnose BRD.

We performed a series of virtual trials to improve our understanding of BRD and customize the existing algorithms for Australia. The virtual trials use this novel, existing data analysed in a variety of manners to answer key questions regarding the relationship between specific cattle behaviours and BRD, as well as animal welfare related outcomes. The REDI algorithms were generated for U.S. cattle and these can be calibrated and optimized for the greater accuracy of detecting BRD in the Australian environment. Results would include an improved fundamental understanding of behaviours associated with BRD and animal welfare offering value to Australian production systems using conventional diagnostic methods as well as identifying areas to prioritize when evaluating new disease detection technologies.

2.2 Specific Objectives

(1) Evaluate existing data from two Australian feedlots (MLA project B.FLT.0242) to determine potential associations between pleurisy/consolidation scores and carcass outcomes
(2) Description of individual animal differences in activity and feeding patterns associated with changes in pulmonary lesions at harvest to quantify expected changes and inform producers of potential animal observations that could improve diagnostic ability.
(3) Characterization of group (pen) level changes in behavioural patterns and associations with pen level disease risk and pulmonary outcomes to quantify behavioural differences that could be used as group thresholds for further evaluation in clinical diagnostics and animal welfare.
(4) Selection and optimization of REDI algorithms for the Australian cattle production system and dynamic platform to customize the sensitivity and specificity based on changes in risk level among calf groups and over time.

3 Methodology

3.1 Initial data management

Data from previous trial were analysed and the dataset limited to include only cattle that did not die or were removed from study. Only cattle that had a lung or pleurisy score were included in the analysis. A total of 5,919 observations were used in this lung score analysis from two Australian feedyards. Lung scores, in the form of lung consolidation, pleurisy, and abscesses were recorded at the slaughter plant for every animal eligible to be scored. Scoring was performed by the same three people, who were trained prior to initial scoring. Animals that died or were rejected from the trial did not have a lung score recorded. Animals that were condemned also did not have a lung score recorded. If an animal's lungs were stuck to the thoracic wall, a consolidation score was not recorded, but a pleurisy score was. Consolidation was recorded based on a scale of 0-100% (Rezac et al., 2014). Consolidations scores were categorized into three categories, 0-1, 2-9% and 10-55%. Pleurisy scores ranged from 0-3. Score 0 is no pleurisy, score 1 is pleuritic tags between lung lobes, or on the lung surface with no adhesion on the pleura of the thorax, a score 2 was pleuritic lesions with localized adhesion to the thoracic wall, and a score 3 is severe pleuritic adhesions with the chest requiring "Stripping." An animal where the lungs were adhered to the thoracic wall received a pleurisy score 3, but a consolidation score was not recorded (reported as NS). An overall lung score was created based on the combination of consolidation and pleurisy scores.

Not all animals in the dataset had an individual live weight prior to slaughter; however, a hot carcass weight was available. The average dressing percentage on available data of live weight and hot carcass weight was calculated to be 58%. This percentage was used to calculate an estimated live weight for all animals (even if live weight was available to maintain consistency). The estimated live weight, initial body weight, and days on feed were used to calculate an average daily gain over the entire period.

3.2 Statistical Analysis: Comparison of behaviour to carcass

Data were analysed on an individual animal level, using a linear mixed model with the carcass characteristics as the independent variable and lung characteristics (pleurisy, and lung score) as dependent variables. Additional relevant dependent variables (e.g. BRD status, initial weight) were included as fixed effects in each model, and the results are presented for the variable of interest (pleurisy or lung score). Random effects were included in the model to account for yard, induction group, and pen.

3.3 Individual behaviour and wellness

Objective: Utilize data from previous project (B.FLT.0242) to describe individual animal differences in activity and feeding patterns associated with wellness status (healthy or sick) as defined by clinical and pulmonary metrics.

3.3.1 Behavioural data management

Behavioural data were imported into the statistical software and contained 3,651,122 observations (hourly summaries) for the 3,114 cattle representing an average of 48.9 days per head of behavioural monitoring. Key behavioural components were selected to describe cattle behaviour with two variables representing each of three areas in cattle behaviour: activity, proximity to areas of interest, and social

Table 1. Key behavioural variables by behavioural category.

Activity	Proximity to areas of interest	Social Indices
Distance traveled	% time in water zone	Average calves within 3 M
Speed (M/s)	% time in feeding zone	% time zero calves within 3 M

indices (Table 1). These six behavioural variables were aggregated on an hourly level for each calf and used for the raw data in the subsequent analyses.

Data cleaning consisted of removing unrealistic values that may have occurred due to tag losses or hardware issues. Only values considered unrealistic were removed from each behavioural outcome. For distance travelled, values ranged from 0-750 with 12,946 observations removed that were greater than 750. The average speed in meters per second ranged from 0 to 0.75 after data cleaning with 4,620 values removed outside this range. The percent time in the waterzone and feedbunk, and percent time with zero calves within 3 meters ranged from 0 to 100% and data outside these ranges were removed (28 values for each variable). The average number of calves within 3 meters ranged from 0 to 15 with 180 values removed outside this range.

3.3.2 Wellness categorization

Wellness status was generated for all calves and each animal was placed into one of three categories: known healthy (HLTH), known diseased (SICK), or intermediate/uncertain (INTR). Cattle were placed in HLTH if they had no lung or pleurisy score greater than 1, had never been treated for BRD, did not die, and were not rejected for any reason during the trial. Cattle were placed in SICK if they were classified as having a lung or pleurisy score of 3, were treated two or more times and subsequently died/were rejected, died due to BRD, or were rejected from trial due to BRD. All other cattle were placed in the INTR category.

The full dataset contained 3,114 head monitored with the REDI behavioural system. Cattle were placed into each of the wellness status categories based on the combination of lung scores, treatment history and health outcomes. The SICK category consisted of 138 head with 10 rejected for BRD, 8 died from BRD, 14 head treated twice and subsequently rejected, 3 with a lung score of 3 (and lower pleurisy score), and 103 head having a lung or pleurisy score of 3. The HLTH category consisted of 1,508 head that received no BRD treatment and did not have a pleurisy or lung score greater than 1. The INTR category contained 1,468 head encompassing the remainder of the dataset. The distribution of wellness categories by feedyard and pen is displayed in Table 2.

Table 2. Distribution of cattle in each wellness category by arrival yard and pen

Yard	***Pen***	***HLTH hd (%pen)***	***INTR hd (% of pen)***	***SICK hd (% of pen)***	***Total hd***
A	1	117 (39.0%)	171 (57.0%)	12 (4.0%)	300
A	2	112 (37.3%)	177 (59.0%)	11 (3.7%)	300
A	3	193 (64.3%)	102 (34.0%)	5 (1.7%)	300
A	4	230 (76.7%)	69 (23.0%)	1 (0.3%)	300
A	5	217 (72.3%)	76 (25.3%)	7 (2.3%)	300
A	6	166 (55.3%)	127 (42.3%)	7 (2.3%)	300
B	7	86 (39.1%)	116 (52.7%)	18 (8.2%)	220
B	8	88 (39.5%)	119 (53.3%)	16 (7.2%)	223
B	9	85 (39.5%)	117 (54.4%)	13 (6.1%)	215
B	10	99 (45.8%)	106 (49.1%)	11 (5.1%)	216
B	11	54 (24.5%)	150 (68.2%)	16 (7.3%)	220
B	12	61 (27.7%)	138 (62.7%)	21 (9.6%)	220
	Total	1508 (48.43%)	1468 (47.14%)	138 (4.43%)	3114

The wellness categories divided the cattle by health outcomes as displayed in Table 3. The objective to identify behavioural characteristics among sick and healthy cattle is based on a meaningful categorization of final wellness status using a combination of lung scores, pleurisy scores, and health outcomes (BRD treatment status, death or rejection). Standard performance and health outcomes were statistically compared among the wellness categories to determine relative importance of wellness status categorization based on these criteria (Table 4).

Table 3. Percent health outcomes by wellness category.

	HLTH (n=1508)	INTR (n=1468)	SICK (n=138)
Percent treated for BRD	0.0%	61.9%	50.7%
Percent dead	0.0%	1.1%	7.2%
Percent rejected	0.0%	5.7%	15.9%

Table 4. Comparison of common performance characteristics among cattle in each wellness categories using multivariable models.

	HLTH		INTR		SICK		SE	P-value
Initial body weight (KG/hd)	400.85	a	402.37	ab	401	a	34.04	0.49
Weight at REDI tag removal (~d 55, KG/hd)	515.26	b	513.89	ab	506.23	a	5.42	0.03
ADG at REDI tag removal (~d55; kg/hd/d)	2.21	b	2.18	ab	2.04	a	0.2	0.04
Final estimated live weight (kg/hd)	663.22	b	661.34	b	650.67	a	10.96	0.01
Final estimated live ADG (kg/hd/d)	1.74	b	1.74	b	1.54	a	0.31	<0.01
Hot carcass weight (kg/hd)	384.66	b	383.57	b	377.39	a	6.36	0.01

MSA Marbling score	377.93	a	380.25	a	380.47	a	13.95	0.77
Eye muscle area	84.45	a	84.27	a	84.99	a	1.32	0.58

Superscripts within a row indicate statistical differences at P< 0.05

*Each model contained relevant covariates of interest and effects to account for lack of independence among data points.

3.3.3 BRD Treatment timing

The dataset consisted of cattle identified and treated for BRD based on REDI. These data were augmented by the newly created wellness categorization and the timing of illness based on cattle confirmed sick and in the intermediate category could be compared (Figure 1).

Figure 1. Distribution of timing of animals treated the first time for BRD based on REDI classification in cattle that had a wellness categorization of INTR or SICK.

Figure 1a. Percent of first treatments by days on feed.

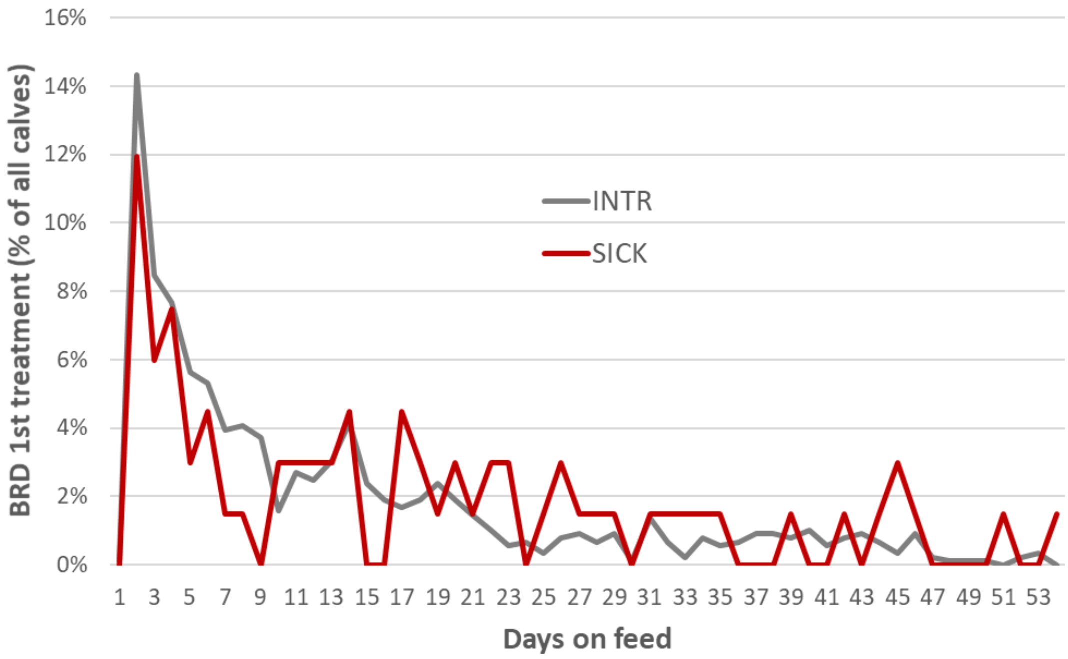
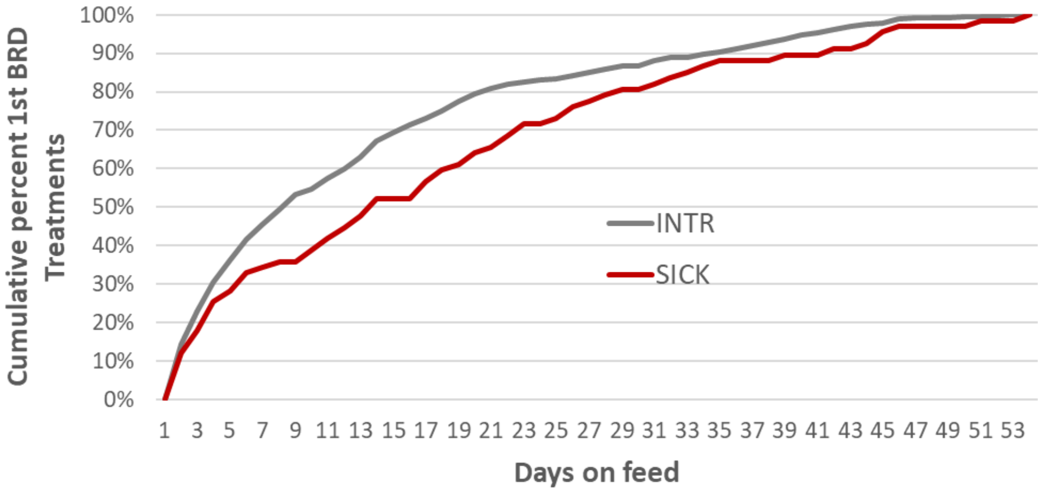


Figure 1b. Cumulative percent of first treatments by days on feed.



Most of the cattle were identified for illness early in the feeding phase with a large percent in the first week on feed and 76% of cattle confirmed sick were identified by 28 days on feed. The SICK cattle that were treated based on REDI represented a smaller number of cattle than the INTR cattle treated by REDI. Thus, the line comparing daily probability of pulls by wellness category is more sporadic for the SICK group. In both charts the lines are similar and may mean the SICK cattle were a subset of the overall population identified for disease. Alternatively, some of the INTR cattle may have benefited from treatment for disease and not ended the feeding phase in the SICK category.

3.3.4 Statistical analysis comparing individual behaviour to health outcomes

Descriptive analyses were performed on the final dataset using both hourly observations and aggregated to the individual calf. A subset of the data was created containing only calves with known outcomes of healthy or sick based on defined wellness category criteria. Multivariable statistical models were created to evaluate relationships between key behavioural variables and potential covariates of interest including wellness status (sick or healthy), days on feed, hour of day, breed, and initial body weight. Each statistical model accounted for lack of independence among observations due to feedyard, pen, and individual calf. Due to the data quantity, independent statistical models were created for the first 28 days on feed to determine potential associations between covariates and each behavioural variable. The objective of these models was to describe individual animal differences in activity and feeding patterns associated with each wellness category (HLTH or SICK) and inform producers of observations that could improve diagnostic ability. Individual statistical models were created for each of the key behavioural variables.

3.4 Characterization of pen-level behavioural changes

Objective: Utilize data from previous project (B.FLT.0242) to characterize group (pen) level changes in behavioural patterns and associations with pen level disease risk and pulmonary outcomes to quantify behavioural differences that could be used as group thresholds for further evaluation in clinical diagnostics and animal welfare. These results will be useful for determining thresholds and metrics for monitoring changes in group behaviour.

3.4.1 Pen-level behavioural data

Behavioural data from the previous study were aggregated to the calf group and day level creating a dataset with behavioural records for each calf group for each day on feed. A calf group was defined as a group of animals that entered the study at the same time period and were housed within the same pen. Key behavioural components were selected to describe cattle behaviour with two variables representing each of three areas in cattle behaviour: activity, proximity to areas of interest, and social indices (Table 1). These six behavioural variables were aggregated on a daily for each calf group and used for the raw data in the subsequent analyses. The objective was to identify potential thresholds for behavioural changes associated with differences in calf group health status; therefore, additional variables were created representing a one- or three-day lag of each of the key behavioural variables.

Weather data were collected from www.worldweatheronline.com using the closest location to each of the feeding facilities. For each day on feed for each calf group the minimum temperature, maximum temperature and precipitation amount was recorded. Lag variables of one- and three-days were also created for each of the weather variables.

3.4.2 Pen-level wellness categorization

Disease status for individual calves was classified based on the previously created criteria, and each animal was placed into one of three categories: known healthy (HLTH), known diseased (SICK), or intermediate/uncertain (INTR). Cattle were placed in HLTH if they had no lung or pleurisy score greater than 1, had never been treated for BRD, did not die, and were not rejected for any reason during the trial. Cattle were placed in SICK if they were classified as having a lung or pleurisy score of 3, were treated two or more times and subsequently died/were rejected, died due to BRD, or were rejected from trial due to BRD. All other cattle were placed in the INTR category.

Wellness outcomes were monitored for this trial based on the individual calf classification (SICK or INTR) or if the cattle had been treated for BRD (the total of SICK and INTR). Mortalities and rejects were also monitored on each calf group. Table 5 displays the health outcomes for each calf group.

Table 5. Distribution of health outcomes for each calf group.

Calf Group	***Yard***	***Total hd***	***BRD 1st treat hd***	***%***	***SICK hd***	***%***	***INTR hd***	***%***	***Mortality hd***	***%***	***Rejects hd***	***%***
94	B	220	68	30.9%	5	2.3%	63	28.6%	0	0.0%	16	7.3%
106	B	300	158	52.7%	8	2.7%	150	50.0%	3	1.0%	1	0.3%
107	A	293	149	50.9%	10	3.4%	139	47.4%	4	1.4%	2	0.7%
109	A	220	51	23.2%	1	0.5%	50	22.7%	4	1.8%	1	0.5%
110	B	223	84	37.7%	10	4.5%	74	33.2%	0	0.0%	16	7.2%
117	B	215	64	29.8%	4	1.9%	60	27.9%	0	0.0%	7	3.3%
121	A	300	0	0.0%	0	0.0%	0	0.0%	0	0.0%	0	0.0%
139	B	216	59	27.3%	7	3.2%	52	24.1%	1	0.5%	14	6.5%
142	B	220	75	34.1%	5	2.3%	70	31.8%	0	0.0%	17	7.7%
143	B	220	74	33.6%	8	3.6%	66	30.0%	0	0.0%	17	7.7%
149	A	300	61	20.3%	5	1.7%	56	18.7%	0	0.0%	1	0.3%
155	A	300	110	36.7%	4	1.3%	106	35.3%	3	1.0%	1	0.3%
Grand Total		3027	953	31.5%	67	2.2%	886	29.3%	15	0.5%	93	3.1%

3.4.3 Pen-level statistical analysis

Descriptive analyses were performed on the final dataset using daily calf group averages and aggregated to the individual calf group. Multivariable statistical models were created to evaluate potential relationships between outcomes of interest (days with BRD pulls > 1% of pen, increases (>0.5%) or decreases (<-0.5%) in the pull rate between days) and potential covariates of interest including days on feed, key behavioural and weather variables. Each statistical model accounted for lack of independence among observations due to feedyard. The objective of these models was to describe calf group level daily differences in activity and feeding patterns associated with each disease events of interest and inform producers of observations that could improve diagnostic ability.

3.5 Data management for algorithm evaluation

Data from previous trials were evaluated to determine the fit of each algorithm by running virtual trials on each data set. For each virtual trial, raw data were processed as if receiving individual hourly behavioural data from each calf in each pen in real time; therefore, all raw behavioural data were re-evaluated for each of the new algorithms. The raw data set consisted of 3,441,010 individual hourly records to be processed for each virtual trial. Each hourly record contained behavioural information on each calf.

Algorithms from the previous study were applied to the behavioural data for evaluation and refinement. Each algorithm resulted in a probability of illness for each hour for each calf. These data were utilized to determine validity and diagnostic characteristics of each algorithm when applied to each hour. A stepwise process was employed including using known calf outcomes (the illness classification system mentioned above) in a training data set. The initial evaluation used receiver operating characteristic (ROC) curves to determine the most appropriate threshold for illness determination for each study hour. As this step was utilized to enhance diagnostic sensitivity, the subsequent phase worked to create the number of hours which the threshold must be breached within a 24-hour period to trigger an alert. The second phase focused on optimizing diagnostic specificity. In aggregate, these new thresholds and hourly results were applied to the data to determine the results of each algorithm or combination of algorithms.

Disease status for individual calves was classified based on the previously created criteria, and each animal was placed into one of three categories: known healthy (HLTH), known diseased (SICK), or intermediate/uncertain (INTR). Cattle were placed in HLTH if they had no lung or pleurisy score greater than 1, had never been treated for BRD, did not die, and were not rejected for any reason during the trial. Cattle were placed in SICK if they were classified as having a lung or pleurisy score of 3, were treated two or more times and subsequently died/were rejected, died due to BRD, or were rejected from trial due to BRD. All other cattle were placed in the INTR category.

The goal of the training data set was to evaluate cattle in known outcome periods. Data were aggregated creating individual records for each calf and each hour for the entire period including overall classification of the calf based on the above criteria and the probability of illness as determined by each algorithm and combination of algorithms. Data were further limited to include only cattle that were classified as HLTH or SICK resulting in 1,852,645 hourly records for calves in the trials. Data were on an hourly level; therefore, behavioural data were recorded on calves classified as SICK during the entire trial period. To optimize the disease calls, a training dataset was created with only SICK cattle limited to 3 days prior to, the day of, and three days after being treated for BRD the first time. The sick cattle data set resulted in 7,911 hourly observations from 66 calves. (because these data were limited by time scope relative to BRD treatment, only SICK calves treated for BRD were included in this analysis). The HLTH data represented 1,711,556 hours of healthy data from 1486 calves throughout the trial period.

The training dataset was used to calculate density charts representing the number of hours for calves classified as SICK or HLTH and the relative probability of each algorithm at calling them diseased for that hour. These charts show overlap in many hours of the sick and healthy calves. (Figure 1). The overlap is not surprising given the relatively subtle differences in behaviour and the fact that the training data set included data from a 7-day period for sick cattle surrounding the actual time of disease. It is likely that a portion of this period included healthy behaviours while only a subset included the true time of illness. A more refined definition of the specific time the cattle were sick would enable an enhanced evaluation of differences in illness. The probability of illness and wellness also overlap in these charts illustrating no single algorithm or variable provides perfect distinction between illness and health. Similar to evaluation of any diagnostic test, the differences must be discerned based on ideal thresholds of probability to optimize diagnostic accuracy.

4 Results

4.1 Comparison behaviour to carcass

4.1.1 Descriptive Analysis

The full dataset contained 6,227 head and 308 head were removed that were either dead (n=55) or removed from the trial. The overall BRD morbidity in the cattle was 30.6% (n=1906 treated) and total mortality of 0.8% (n=55). After removal of the dead and rejected cattle a total of 5,919 observations were included in lung score analysis. Descriptive analysis revealed 61.7% of cattle cattle had pleurisy score greater than zero. The overall level of abnormal (>0) pleurisy scores was higher than expected. Previous research in South Africa found that lung lesions were present in 43% of calves at slaughter with 38.8%% showing pleurisy lesions in a group with 22.6% treated for BRD (2006 Thompson JAS 84(2): 488-498). Evaluations in the US illustrated 67.3% of cattle had no pulmonary lesions (2014, Rezac et al. JAS 92(6): 2595-2602). The overall level of abnormal lesions in these data were surprising, although the number of cattle in the most severe grouping (pleurisy score 3) was 3.2% (n=192), and this is closer to the expected number of severe cases in groups with relatively low overall morbidity.

Most cattle (65.5%) had lung consolidation scores greater than zero. There were a greater number of no score (NS) cattle in the lung consolidation category, and this was influenced by the scoring methodology. If cattle received a pleurisy score of 3 a NS was recorded on the lung consolidation score (representing 115 head). Therefore, these NS cattle would be considered severely affected. The number of abnormal lung consolidation scores were also higher than expected given comparisons to previous work and the level of morbidity in the group.

Table 6. Number of cattle in each combined lung score category (pleurisy / lung consolidation).

	Pleurisy				
Consolidation	**0**	**1**	**2**	**3**	**NS**
0 (0%)	1025	805	194	19	
1 (1-10%)	1157	1399	708	15	
2 (11-49%)	74	77	154	8	
3 (>50%)	1	3	6	1	
NS	6	0	3	149	115

The scores were combined into a single variable representing a combination of pleurisy score and lung consolidation category. The number of animals represented in each level is presented in Table 6. Only 17.3% (n=1025) of cattle received a lung consolidation score of 0 and a pleurisy score of 0. Of those cattle, 447 (43.6%) had been treated for BRD based on clinical signs. There were 5.5% (326) of cattle receiving a pleurisy score 3 or lung consolidation score 3 or NS on both. Of these cattle in the more severe category 32.8% (107) were treated for BRD. The lack of agreement among clinical illness status is not surprising as this has been reported in studies comparing clinical illness and lung scores (2009, White and Renter, JVDI; 2016 Timsit et al. Prev Vet Med 135:67-73). Accurate classification of health status may be dependent on combining clinical status and lung / pleurisy scores to place cattle into categories of likely healthy or likely ill.

4.1.2 Comparison of pulmonary scores and carcass outcomes

The outcomes of pleurisy, lung consolidation score, and the combined score were evaluated for potential relationships to each carcass variable. Each model included effects to control for the hierarchical nature of the data (calves within pens, induction groups and individual feedyards).

The final multivariable models for hot carcass weight included covariates for initial body weight, BRD treatment status, breed, and DOF at harvest. Treatment group (REDI or control) was not significant (P=.35) and thus was removed from the statistical models. The hot carcass weight was significantly associated with lung consolidation and pleurisy (Figure 2). For pleurisy, the HCW was lowest if the cattle were not scored or received a score of 3. This illustrates that in severe cases the reduction in carcass weight can not only be significantly associated with pleurisy, but also a meaningful difference as the numerical difference was nearly 10 kg. Lung scores illustrated a similar pattern with NS cattle having the lowest HCW. In both lung scores and pleurisy, cattle that were in a higher lung score category had higher HCW compared to cattle with no lesions (0). This result was unexpected.

Fig 2. Hot carcass weight by lung scores (A) and pleurisy scores (B). Bars that differ by letters indicate a significant ($P < 0.05$) difference among levels.

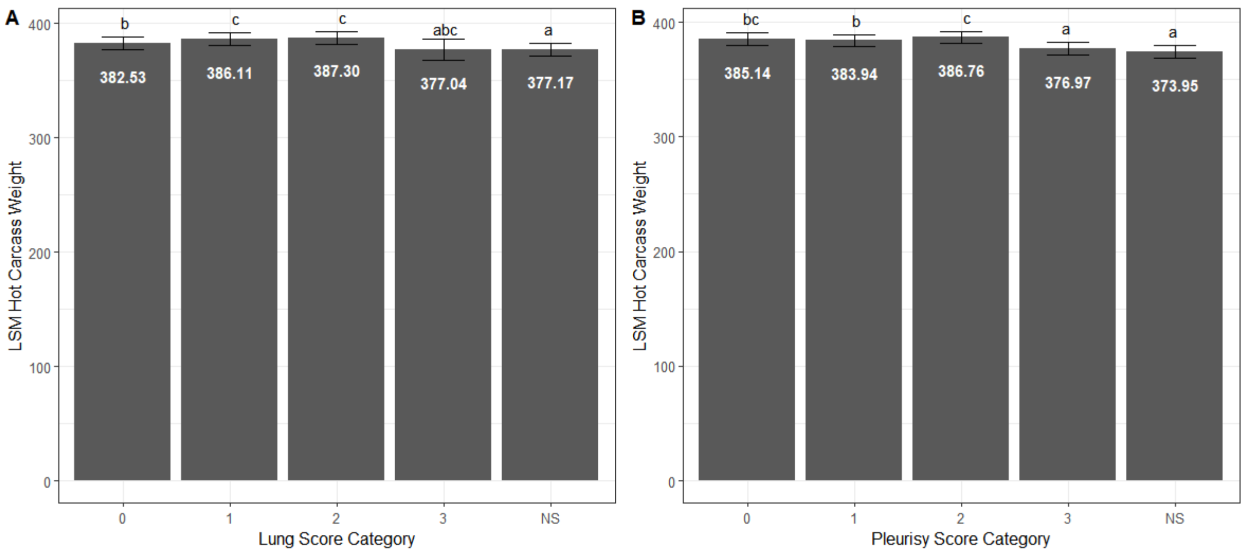


Table 7. Statistical comparison of consolidation and pleurisy score on hot carcass weight (HCW). Rows that differ by letters indicate a significant ($P < 0.05$) difference among levels.

Lung Score	lsmean	SE	Letters		Pleurisy	lsmean	SE	Letters
0	382.5	5.5	b		0	385.1	5.2	bc
1	386.1	5.5	c		1	383.9	5.2	b
2	387.3	5.7	c		2	386.8	5.3	c
3	377	9.1	abc		3	377	5.5	a
NS	377.2	5.7	a		NS	374	5.7	a
p < 0.01					p < 0.01			

The final multivariable models for average daily gain included covariates for initial body weight, BRD treatment status, breed, and DOF at harvest. Treatment group (REDI or control) was not significant (P=.26) and thus was removed from the statistical models. The average daily gain was significantly associated with lung consolidation and pleurisy.

The calculated average daily gain was also associated with lung consolidation score, pleurisy score and overall lung score. Similar to hot carcass weight, cattle with lung score of NS had lower ADG. Cattle with pleurisy score 2 had higher rate of gain than the rest of the cattle and cattle with pleurisy score 3 or NS had lower rates of gain. The marbling scores (MSAMarb) were not significantly associated with lung scores (P=0.72), pleurisy scores (P = 0.15) or combination lung scores (P = 0.67). These models included significant effects for breed, initial body weight, BRD treatment status, and hierarchical effects for observations within pens, induction groups and feedyards.

The model for P8Fat contained effects for breed, initial body weight, BRD treatment status, days on feed and hierarchical effects. There was a significant association between P8Fat and both lung score (P = 0.05) and pleurisy score (P = 0.05). Despite the overall association, there were no statistical (P < 0.05) differences among levels although both pleurisy and lung score of 3 had lower numerical values. The combined lung score category was not (P=0.13) significantly associated with P8Fat. The relationship between EMA and lung scores tended (P = 0.08) to be significant in a model containing initial body weight, BRD treatment status, days on feed and hierarchical effects. The relationship between EMA and pleurisy scores or the combined lung score were not significant.

Ossification was not significantly associated with lung scores (P=0.22), pleurisy scores (P = 0.60) or combination lung scores (P = 0.59). The carcass pH was not significantly associated with lung scores (P=0.37), pleurisy scores (P = 0.71) or combination lung scores (P = 0.49). Ribfat was not significantly associated with lung scores (P=0.43), pleurisy scores (P = 0.50) or combination lung scores (P = 0.24). These models included significant effects for breed, initial body weight, BRD treatment status, and hierarchical effects for observations within pens, induction groups and feedyards.

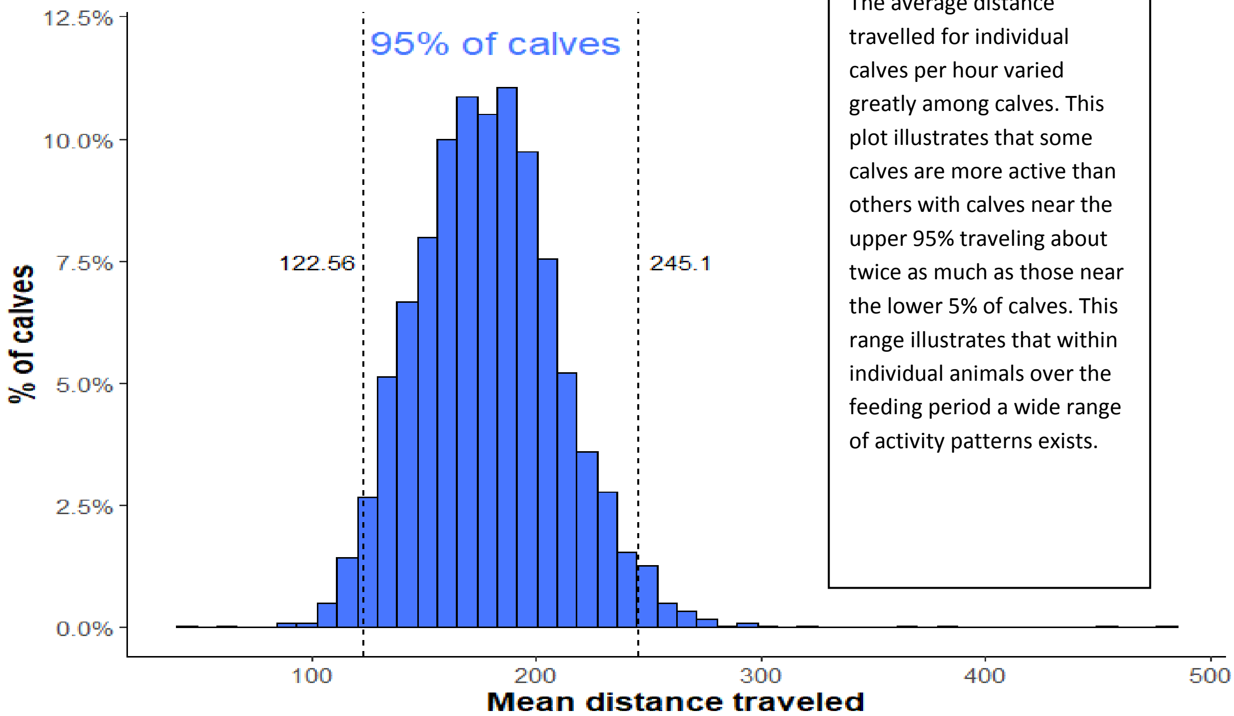
4.2 Comparison of individual behaviour to health outcomes

4.2.1 Calf-level variability in key behavioural variables

Data were evaluated on a per calf basis analysing the average values in key behavioural variables for individual calves over the entire feeding period. This analysis was focused on the individual animal level because calves range in their level of activity, social behaviour, and propensity to eat. These descriptions allow an evaluation of the expected range among individual calves regarding the behavioural traits analysed. Data were aggregated to a calf level providing mean values for each animal to illustrate potential differences related to individual variability. To describe these data histogram plots were created illustrating the values of each behavioural variable that encompassed 95% of the calves (Figure 3).

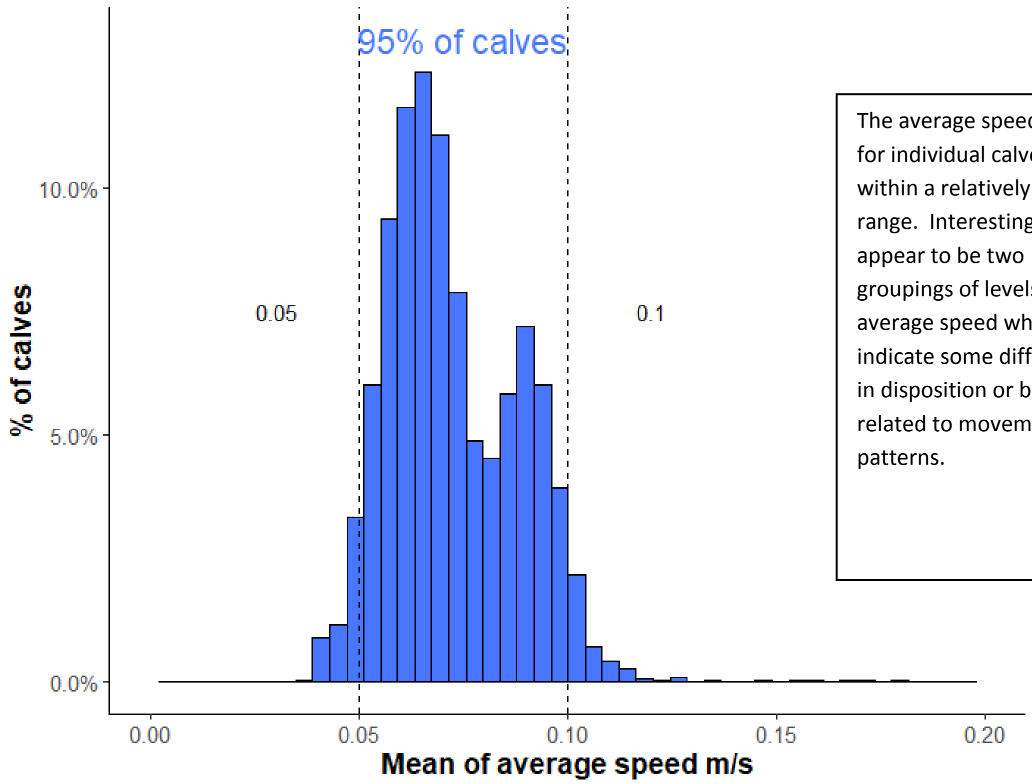
Figure 3. Histograms of key behavioural variables based on data aggregated to an individual calf level over the entire feeding period.

Figure 3 a. Histogram of aggregated individual calf data for distance travelled (m).



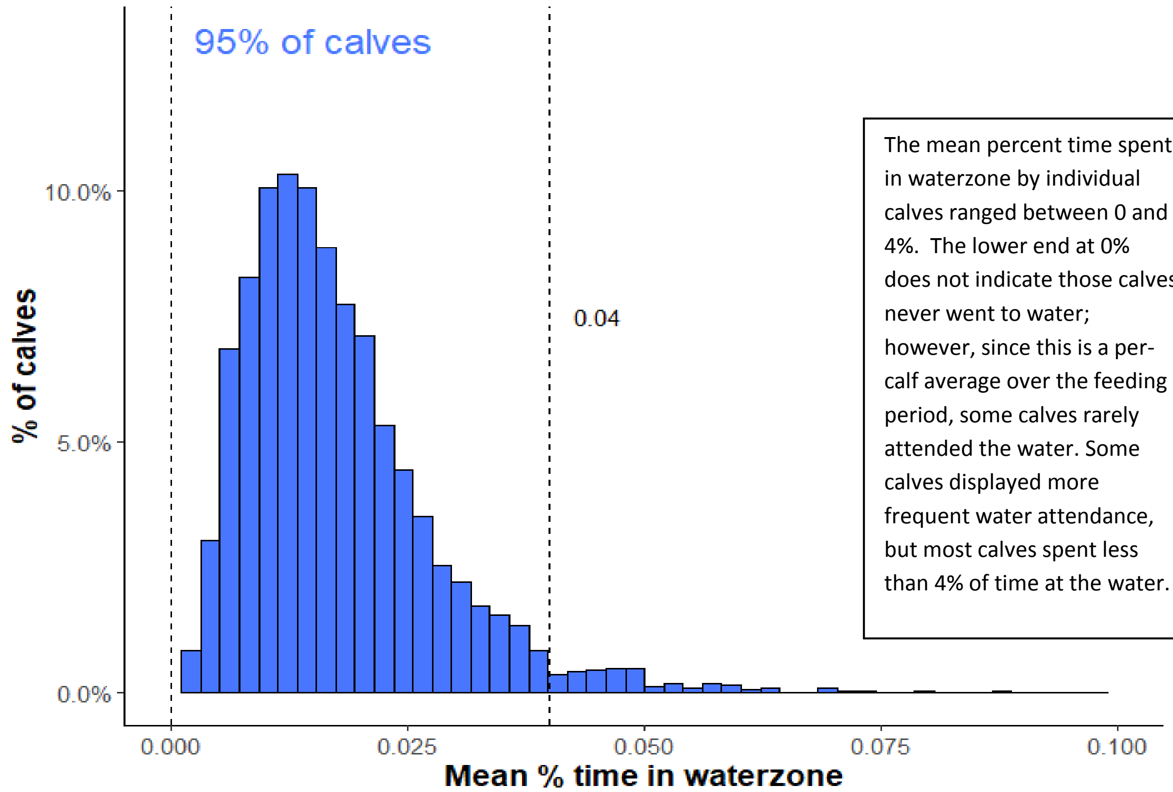
The average distance travelled for individual calves per hour varied greatly among calves. This plot illustrates that some calves are more active than others with calves near the upper 95% traveling about twice as much as those near the lower 5% of calves. This range illustrates that within individual animals over the feeding period a wide range of activity patterns exists.

Figure 3b. Histogram of aggregated individual calf data for average speed in meters per second.



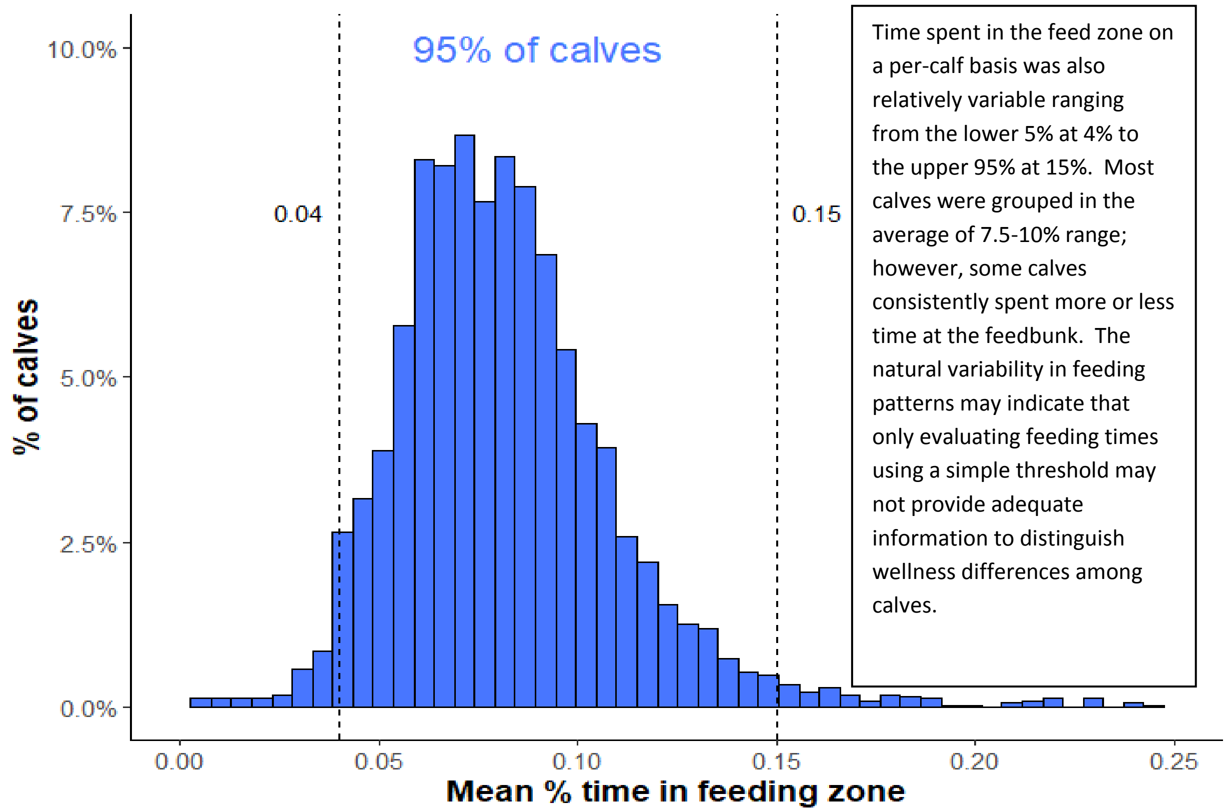
The average speed moved for individual calves varied within a relatively tight range. Interestingly, there appear to be two groupings of levels of average speed which may indicate some differences in disposition or breed related to movement patterns.

Figure 3c. Histogram of aggregated individual calf data for average time in the water zone.



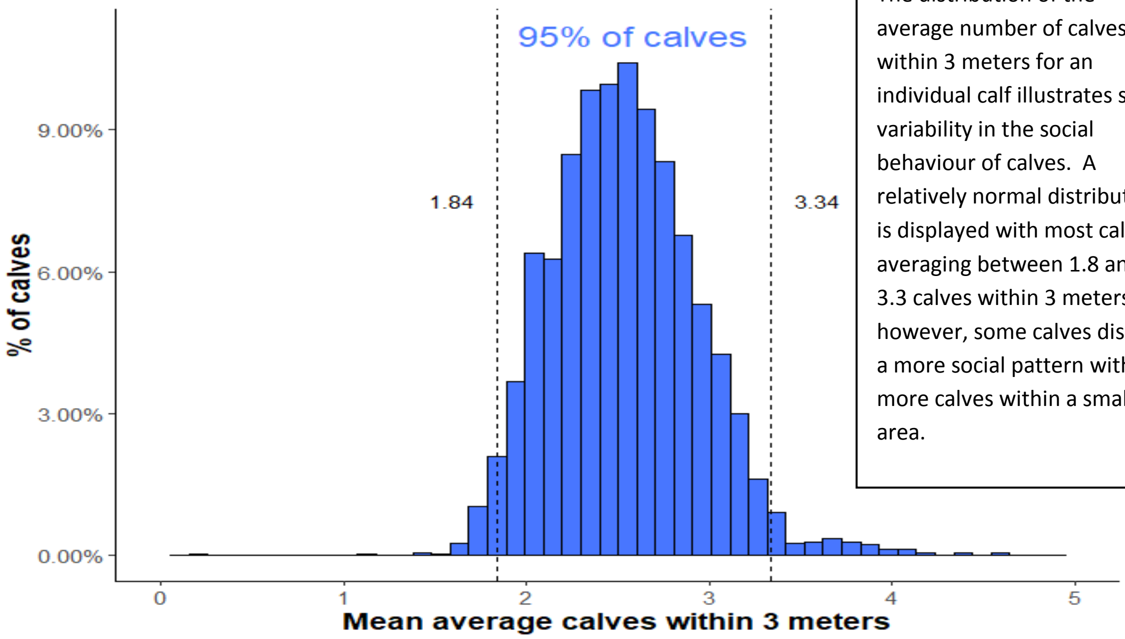
The mean percent time spent in waterzone by individual calves ranged between 0 and 4%. The lower end at 0% does not indicate those calves never went to water; however, since this is a per-calf average over the feeding period, some calves rarely attended the water. Some calves displayed more frequent water attendance, but most calves spent less than 4% of time at the water.

Figure 3d. Histogram of aggregated individual calf data for average time in the feeding zone.



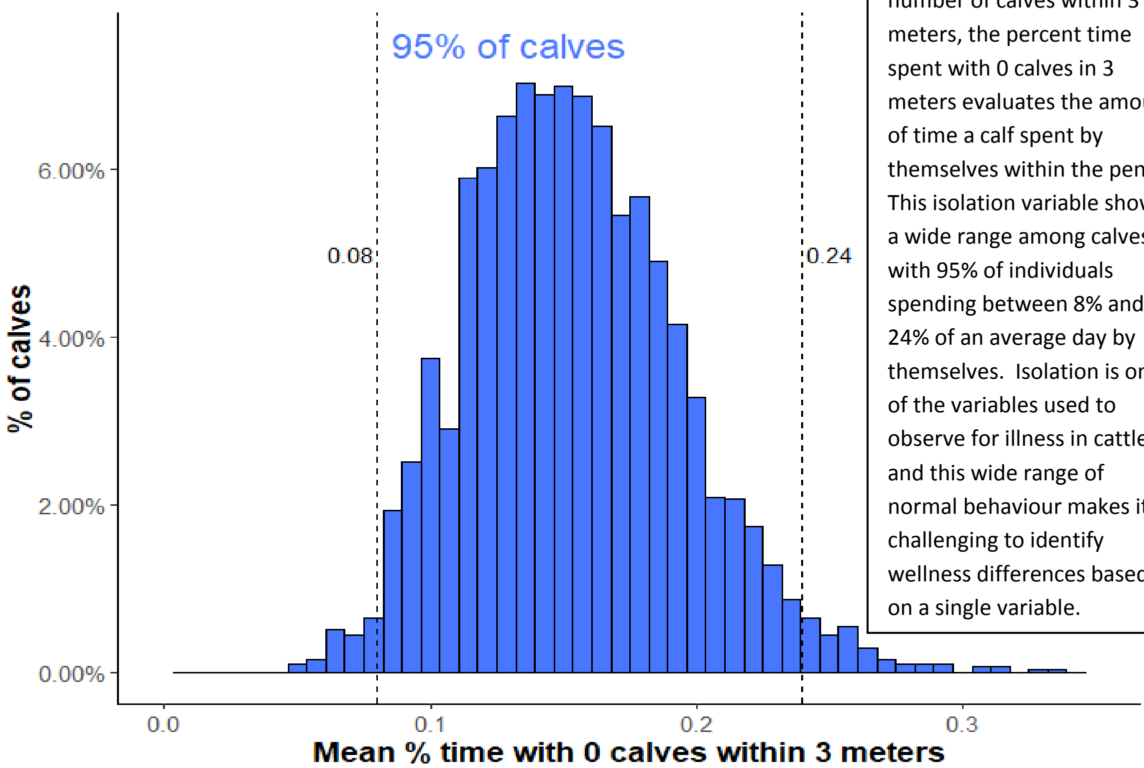
Time spent in the feed zone on a per-calf basis was also relatively variable ranging from the lower 5% at 4% to the upper 95% at 15%. Most calves were grouped in the average of 7.5-10% range; however, some calves consistently spent more or less time at the feedbunk. The natural variability in feeding patterns may indicate that only evaluating feeding times using a simple threshold may not provide adequate information to distinguish wellness differences among calves.

Figure 3e. Histogram of aggregated individual calf data for the average number of calves within 3 meters.



The distribution of the average number of calves within 3 meters for an individual calf illustrates some variability in the social behaviour of calves. A relatively normal distribution is displayed with most calves averaging between 1.8 and 3.3 calves within 3 meters; however, some calves display a more social pattern with more calves within a small area.

Figure 3f. Histogram of aggregated individual calf data for the percent time spent with no calves within 3 meters.



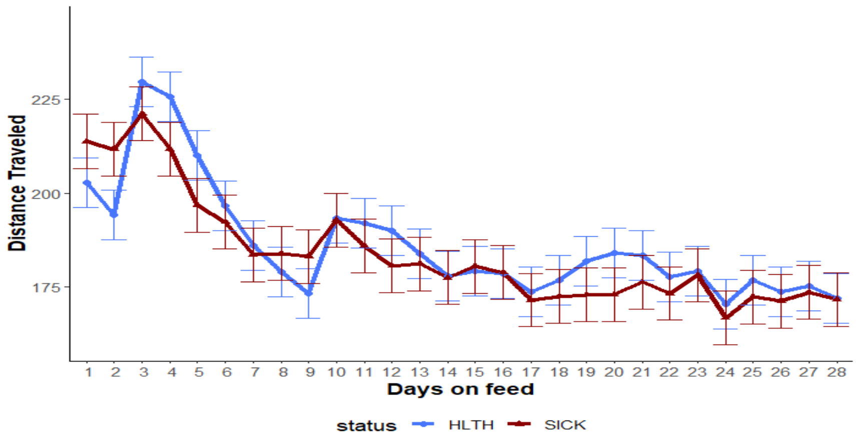
In contrast to the average number of calves within 3 meters, the percent time spent with 0 calves in 3 meters evaluates the amount of time a calf spent by themselves within the pen. This isolation variable shows a wide range among calves with 95% of individuals spending between 8% and 24% of an average day by themselves. Isolation is one of the variables used to observe for illness in cattle and this wide range of normal behaviour makes it challenging to identify wellness differences based on a single variable.

4.2.2 Statistical Analyses by Distance travelled

Distance travelled was significantly associated with breed and initial body weight. The effect of days on feed and hour of the day on distance travelled were modified by calf wellness status (Figure 4).

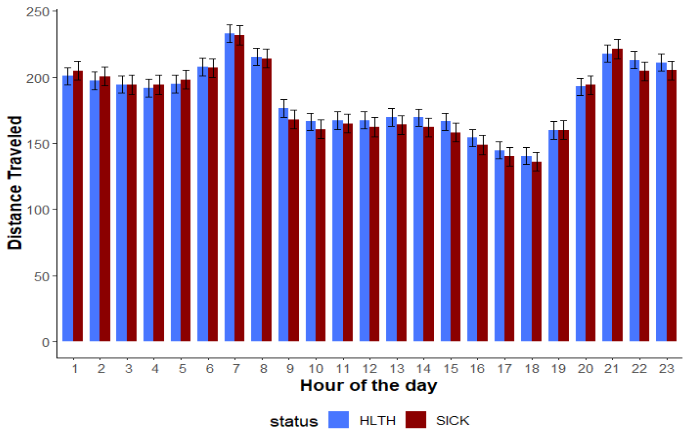
Figure 4. Results from multivariable model evaluated impact of distance travelled.

Figure 4.a. Distance travelled was modified by days on feed and wellness status.



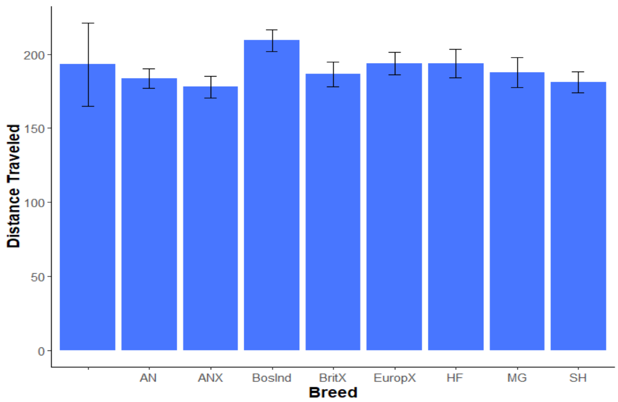
Data included all SICK and HLTH calves as identified in each wellness category regardless of when or if cattle had been identified as diseased. Interestingly, the sick calves displayed greater distance travelled relative to healthy calves in the first few days on feed, then lower distances travelled on days 4 and 5. Values were similar among the two groups for most of the remaining period. Few differences were identified following day 28.

Figure 4.b. Distance travelled by record hour and wellness status (first 28 DOF).



While a significant interaction between record hour and wellness category exists, relatively few differences are present among individual hours. One area to note is cattle have high activity times (8-9 am and 11 pm to midnight). During these high activity times the distances travelled are very similar among calves in each wellness category. This may be due to the fact that social pressures are highest during these time periods and even sick cattle move with the group. During lower activity times (mid-day) more separation was present between activity levels in HLTH and SICK calves. One conclusion may be that the best time to try to observe potential differences in wellness status is likely a time when baseline activity levels are lower and social pressures may not be present.

Figure 4.c. Distance travelled differences by breed (first 28 dof; No label = Undefined breeding; AN = Angus, ANX = Angus Cross; BosInd = Bos indicus; Brit X = British cross; EuropX = European cross; HF= Hereford; MG= Murray Grey; SH = shorthorn).



Differences in baseline activity level were associated with breed, but not modified by wellness category. The Bos Indicus (BosInd) breeds tended to have higher activity levels than other breeds with other breeds displaying similar distances travelled.

4.2.3 Statistical Analyses by Average speed meters per second

The average speed in meters per second was also impacted by breed, initial body weight, and the effects of days on feed and record hour were modified by wellness status. An interaction (P<0.01) was present with days on feed and wellness status related to average speed in meters per second; however, few meaningful trends exist over the days on feed. Similar to distance travelled, sick cattle had numerically lower speeds during days 4-6 on feed, but few within day differences existed in the first 28 dof. After the first few weeks on feed the average speed decreased and stayed similar among the two groups for the remainder of the feeding period.

Similar to distance travelled, cattle displayed higher activity times of day near feeding time and late evening). Slight differentiation was present in the speed of cattle (SICK/HLTH) during the higher activity times when speed was considered. Minimal differences were present in low activity times which is logical given cattle were less active during these periods.

The Bos Indicus breeds displayed higher average speed in meters per second compared to other breeds during the monitoring period. Cattle with unknown breed exhibited high variability.

4.2.4 Statistical analysis by percent time in water zone

The average percent time in the waterzone was associated with initial weight, breed, and the effects of days on feed and record hour were modified by wellness status. The average percent time in the water zone displayed several differences among calves classified as HLTH vs. SICK. Early in the feeding phase (d 2-5) cattle eventually identified as sick illustrated greater percent time at water compared to cattle that were not afflicted with BRD. This could be due to several potential factors including acclimatization to the new environment, or perhaps these cattle entered the facility at some level of dehydration and had increased consumption. The location system only displays that they attended the water area, but cannot differentiate if they drank or not.

Figure 5.a. Average percent time in waterzone by days on feed and wellness status.

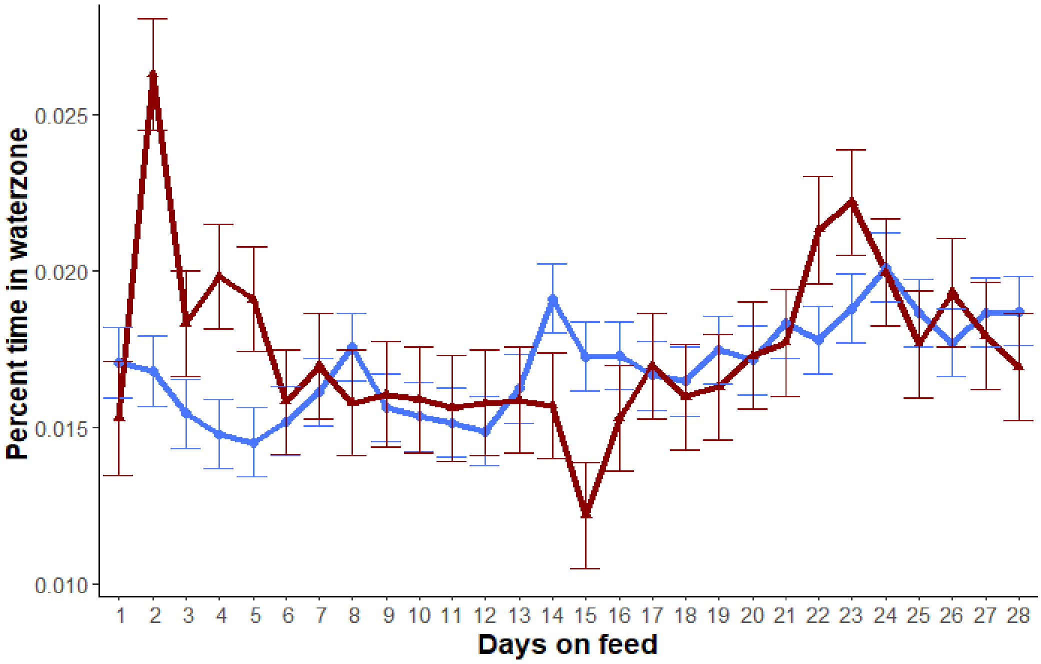
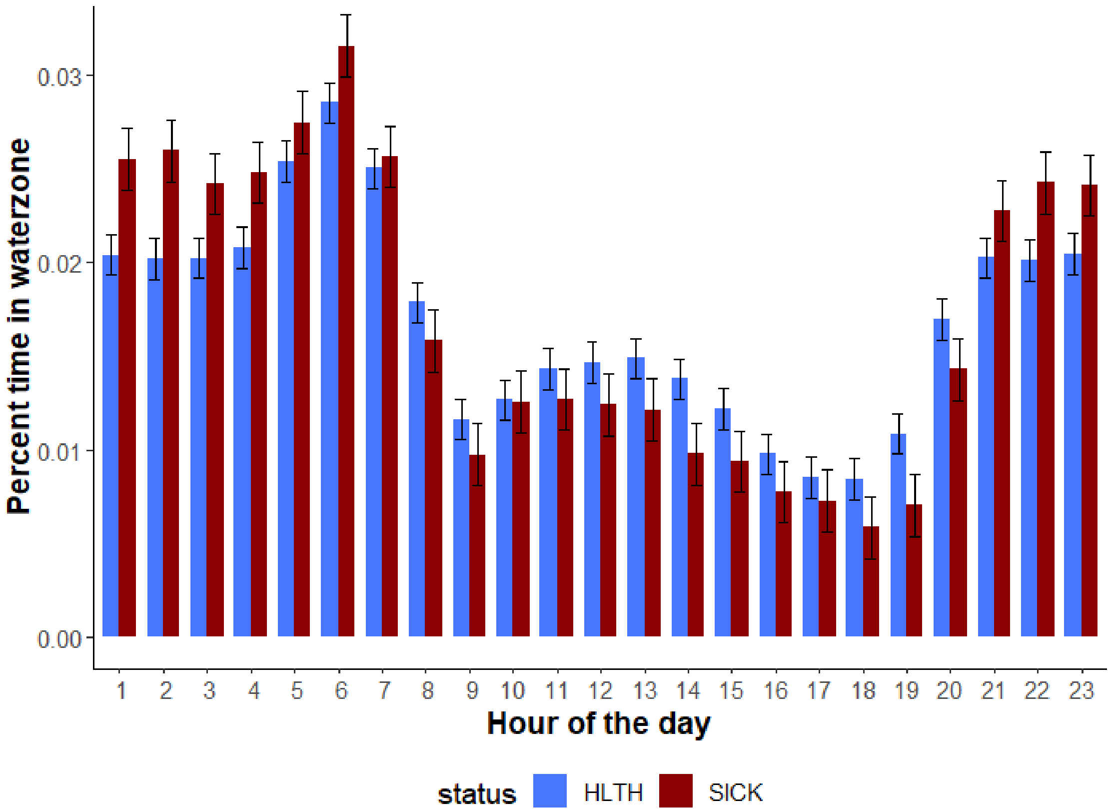


Figure 7.b. Average percent time in waterzone by record hour and wellness status (first 28 DOF).



The time in waterzone pattern between SICK and HLTH calves displays differences in watering behaviour based on time of day. HLTH calves spent more time at water compared to SICK calves during mid-morning to late afternoon (10 am to 8 pm); however, during nighttime hours SICK calves spent more time at the water. One theory based on past observations is that watering behaviour during the day may be a more social event, yet in evening hours it is based on individual calves. This finding indicates a simple threshold based on time near the location of water may not elucidate the differences in wellness status based on these behavioural patterns.

Watering behaviour also differed by breed. Cattle of unknown breed had highly variable watering behaviour. The Bos Indicus and European Cross breeds had lower mean time spent at water relative to other breeds. These data indicate only mean time spent at water and do not indicate the amount consumed during this period of time, only the time cattle spent at water zone.

4.2.5 Statistical analysis by percent time in feeding zone

The average percent time in the feeding zone was associated with breed, and the effects of days on feed and record hour were modified by wellness status.

Figure 6.a. Average percent time in feeding zone by days on feed and wellness status.

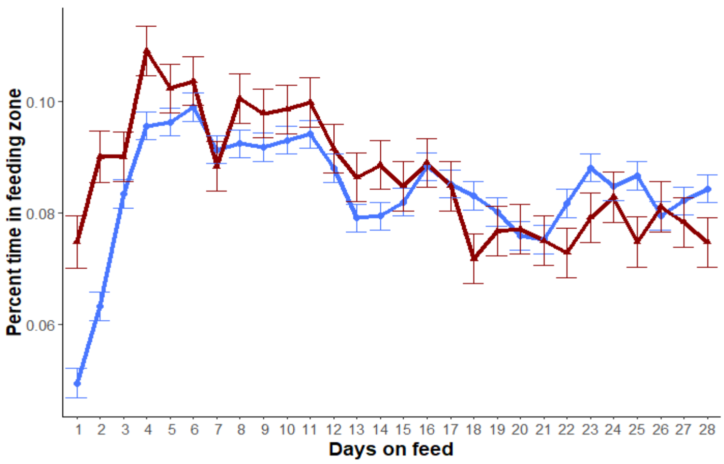


Figure 6.b. Average percent time in feeding zone by record hour and wellness status (first 28 DOF).

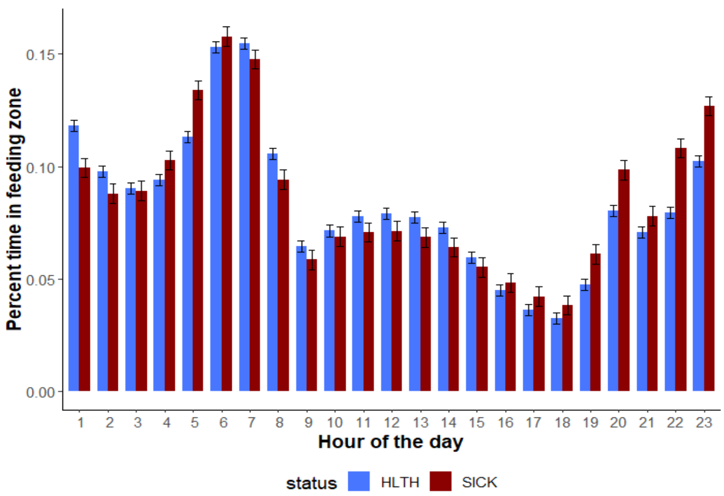
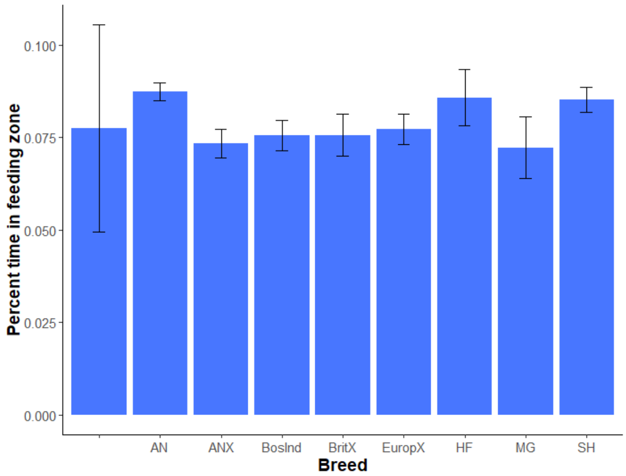


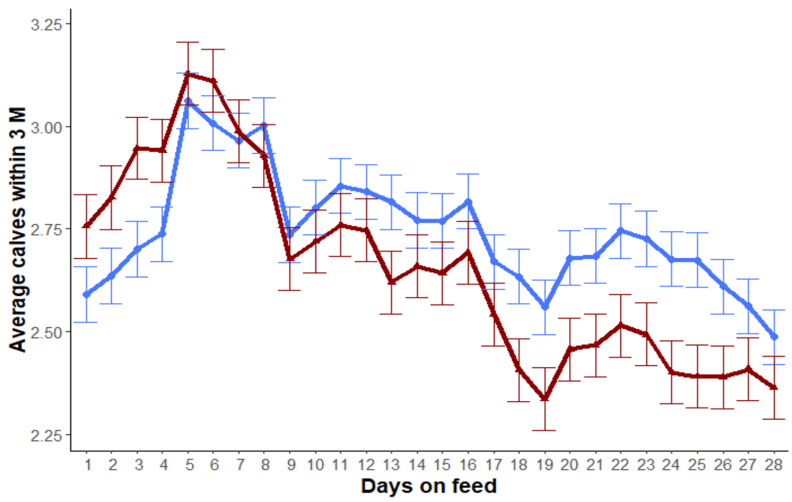
Figure 6.c. Average percent time in feeding zone by breed (first 28 DOF).



4.2.6 Statistical analysis by average number calves within 3 meters

The average number of calves within 3 meters is an indication of socialization and was associated with breed, and the effects of days on feed and record hour were modified by wellness status. The average number of calves within 3 meters (Figure 7a) varied by wellness status and days on feed. At DOF less than 6, sick cattle had higher number of calves within 3 M (more social), but this changed after d 14 when healthy calves had a higher number of calves within 3 M. By d 28 the patterns had equilibrated, and few differences exist based on wellness status. Sick cattle were more social early in the feeding phase (about 45% of illnesses were identified by REDI by 14 DOF) but moved to no difference in social behaviour from other calves later in the feeding phase (after d28).

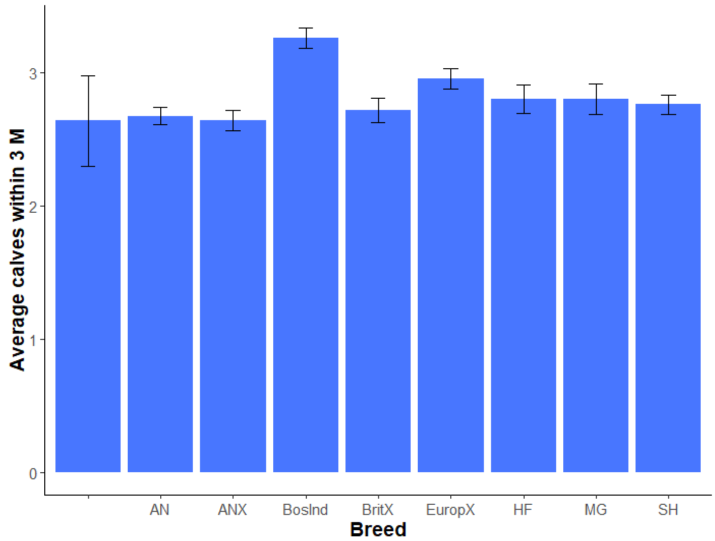
Figure 7.a. Average number of calves within 3 meters by days on feed and wellness status.



Time of day had some effect on the differences in social behaviour based on wellness status with minimal differences noted in mid-day and greater differences noted in the morning and early evening hours. While some of these differences are statistically significant, it would be very hard to observe visually as the average number of calves between sick and healthy may have ranged by 0.1-0.2 calves per hour.

Average number of calves within 3 meters differed by breed with the primary difference being the Bos Indicus cattle had a higher number of calves within 3 meters compared to other breeds. Few differences existed among other breeds.

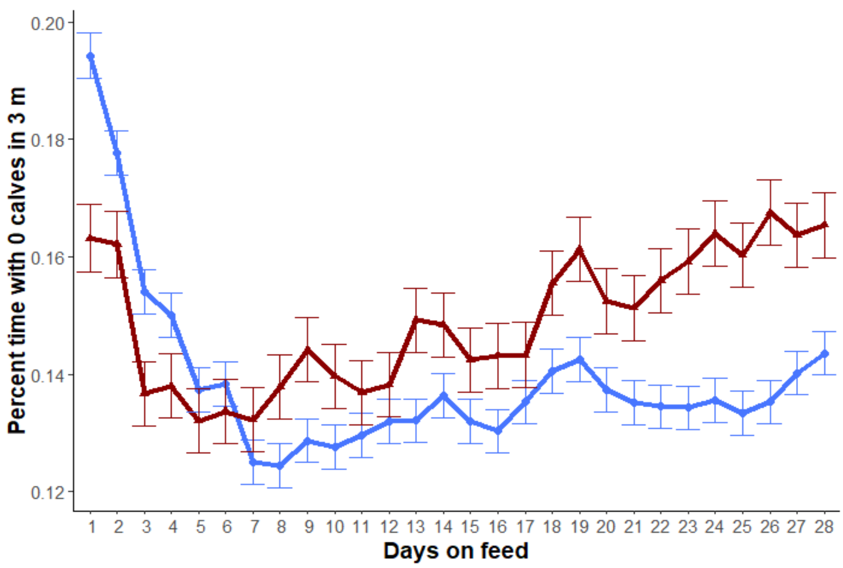
Figure 9.c. Average number of calves within 3 meters by breed (first 28 DOF).



4.2.7 Statistical analysis by percent time with zero calves within 3 meters

The average percent of time with no calves within 3 meters is an indication of isolation and was associated with breed and the effects of DOF and record hour were modified by wellness status (Figure 8). The isolation measure showed that early in the feeding phase (< 5 DOF) cattle that were sick actually spent less time by themselves, but by day 7 they spent more time isolated compared to health calves until about day 50. They spent more time in the group early in the feeding phase and this would be consistent with cattle being prey animals and wanting to hide illness from potential predators. After the inflection point at around day 7, cattle confirmed as SICK spent more time by themselves which aligns with typical expectations for sick calves.

Figure 8.a. Average percent time with no calves within 3 M by days on feed and wellness status.



Time of day was modified by wellness category when evaluating the time animals spent alone. Sick cattle spent more time alone compared to healthy animals; however, this gap was more apparent during high activity times (hrs 7,8, 23,1). Thus, observing for sick calves with isolation behaviour during these time periods could be useful, yet, the magnitude of effect is relatively small (15% time alone for sick cattle in hour 7 compared to 13% time alone for healthy cattle in the same period). Bos Indicus breeds exhibited a lower percent of time spent alone compared to other breeds and minimal differences existed among other breeds.

4.3 Pen level behavioural analysis

Observing the group behavioural patterns illustrates changes in pen density throughout a daily 24-hour period. Cattle display group behavioural patterns relative to position in pen based on proximity to areas of interest such as feed, and water. Changes in differences in behaviour are also related to time of day and likely interaction with temperature and the proximity to shade. Individual pen-level hourly cattle position heat maps were created to visualize the location differences of calves within select pens / days during the study period. Distinct behavioural patterns were identified, but visually no major differences were noted among days with a high number of BRD cases vs. a low number of BRD cases.

Key behavioural variables were evaluated in statistical models to identify potential associations with factors influencing changes in daily calf group-level behaviour. Each model included effects to control for repeated measures on calf groups (over days) and calf groups within each feedyard. The models also included covariates accounting for days on feed, the percent of first BRD pulls on the day of interest, the percent of BRD 1st pulls one day prior, the percent of BRD first pulls averaged over the last 3 days, the deaths per day, and the minimum temperature, maximum temperature, and precipitation on the day of interest, 1 day prior, and 3 days prior. Only variables with a significant ($P < 0.05$) association with the key behavioural outcome of interest were reported.

4.3.1 Pen-level analysis: distance travelled and average speed

Distance travelled was significantly associated with days on feed ($P<0.01$), the 3-day average of BRD 1st pulls ($P < 0.01$), and the maximum temperature ($P=0.05$). Distance travelled decreased over the feeding period as would be expected as cattle became more adjusted to the environment. As the 3-day average percent of BRD first pulls increases, the distance travelled decreased. This is likely due in part to the number of sick animals within the pen, but the behaviour of these treated individuals may have influenced other cattle behaviour within the pen as a significant drop in distance travelled was identified. Higher maximum temperatures resulted in lower average calf group distance travelled and this is likely related to a reluctance to have high levels of activity when ambient temperature is above the thermoneutral zone.

The average speed in meters per second was negatively associated ($P<0.01$) with days on feed indicating a decrease in average speed as days on feed increased. The decreasing speed over time is similar to observations from the individual calves and is likely associated with acclimatization to the feeding environment and social structure. The average calf group speed tended ($P = 0.08$) to be negatively associated with the three-day average of BRD first pulls.

4.3.2 Pen-level analysis time in water and feed zones

The average percent time in the waterzone was associated with the percent of BRD 1st pulls on the day of interest (P<0.01), the three-day average percent of BRD first pulls (P<0.01), minimum temperature (P<0.01), precipitation (P=0.03), and the maximum temperature 1 day prior (P=0.03). The level of BRD 1st pulls influenced the amount of time the calf group spent in the water zone. In both the daily and 3-day average, the greater number of pulls, the lower percent time the entire calf group spent in the water zone. This may provide an early indicator of BRD issues within the pen; however the difference in time at the water moved from ~1.5% when no pulls were present to about 1.0% when abundent pulls were present. This level of change may be difficult to observe without behavioral monitoring systems.

As the minimum temperature increased on the day of interest cattle spent more time in the water zone; this is correlated with the effect that the higher maximum temperatures on the previous day were associated with increased time at the water. Both effects could be related to increased heat load on the animals as the minimum temperature from a day reflects the amount of cooling animals were able to receive and the maximum temperature from the previous day indicates the overall heat load placed on the animal prior to nightfall. Both illustrated that higher temperatures were related to increased time at the water. Higher amounts of precipitation resulted in lower time spent at the water and this may also have been related to heat load with the precipitation having a natural cooling effect which would result in decreased need for water consumption even at the same temperature range.

The average percent time in the feeding zone was associated with days on feed (P <0.01), the previous 3-day average of BRD 1st pulls (P < 0.01), and the maximum temperature (P = 0.02). As days on feed increased, the calf group spent less time in the feed zone. This could be related to the acclimatization to the feeding area and social behaviour. The real time location monitoring system only evaluates the proximity to feedbunk, not actual intake, so as cattle became accustomed to the social structure and feeding pattern they may have consumed more feed in less period of time. The BRD first pulls over the last 3 days had a negative impact on time spent in the feedzone. Although the average 3-day BRD first treatments represents only a small portion of the pen, the time spent at the feed dropped significantly from ~8% to ~6% (a 25% decrease in time at the feed). This may indicate that although clinically ill calves were identified, more cattle in the pen may have been impacted. The increase in maximum temperature also resulted in lower feeding times which is logical given the potential impact of heat and decreased appetite.

4.3.3 Pen-level analysis average calves within 3 M and 0 calves within 3 M

The average number of calves within 3 meters is an indication of socialization and was associated with days on feed (P < 0.01), the number of BRD pulls the previous day (P < 0.01), the maximum temperature (P < 0.01), and the minimum and maximum temperature from three days prior (P < 0.01). As days on feed increased, the calf group average number of calves within 3 meters decreased. This is logical as cattle are herd creatures and early in the feeding phase they are becoming accustomed to both the new environment and social structure. During times of stress cattle may have spent more time in groups, but stayed in smaller groups later in the feeding phase. The number of BRD 1st pulls on the previous day also influence the average number of calves within

3 meters with a positive association between the two variables. This effect may be related to the tendancy for sick cattle to prefer to hide within the group of cattle and spend time in the group following treatment and increasing the average number of calves within 3 meters.

Weather variables impacted the social behaviour of calves with the temperature 3 days prior providing some influence. The higher maximum temperatures 3-day prior resulted in fewer calves within three meters, conversely the higher minimum temperature resulted in more calves within 3 meters. The impact of maximum temperature on the day of interest was inconsistent with the impact on previous days indicating a potential transient impact of temperature changes.

The average percent of time with no calves within 3 meters is an indication of isolation and was associated with days on feed ($P < 0.01$), deaths per day ($P = 0.03$), and the minimum temperature from 3 days prior. The isolation measure showed that calves spent more time alone later in the feeding period. Interestingly, cattle spent more time in isolation on days were 1 or 2 deaths were present in the pen. The minimum temperature from three days prior influenced the percent time alone with lower minimum temperatures leading to more time in isolation.

4.3.4 Pen-level associations with BRD status

Key behavioural variables were evaluated in statistical models to identify potential associations with changes in the calf group health status. The main outcomes of interest were the percent of daily first treatments for BRD. The statistical model included effects to control for repeated measures on calf groups (over days) and calf groups within each feedyard. The models included potential covariates of interest accounting for: days on feed, the percent of BRD 1st pulls one day prior, distance travelled, percent time in feedbunk, percent time in water, average speed travelled in meters per second, number of calves within 3 meters, the percent time with 0 calves within 3 meters, minimum temperature, maximum temperature, and total precipitation. Behavioural and weather variables were included for the current day of interest and the previous day. Only variables with a significant ($P <0.05$) association with the key behavioural outcome of interest were reported.

A statistical model was created to evaluate the daily proportion of BRD treatments and potential associations with behavioural (distance travelled, speed, percent time in water, percent time in feed, average number of calves within 3 meters, percent time with zero calves in 3 meters), health (BRD first pulls the previous day), and weather (maximum temperature, minimum temperature, precipitation). The behavioural and weather variables included the calf group level parameters for the current day of interest and the previous day. The model assessing potential association with the relative proportion of first treatments for BRD daily identified several significant covariates (Table 8).

Table 8. Model results evaluating associations with daily percent 1st BRD treatments.

Variable	Estimate	Std. Error	P-Value	
Days on Feed	-0.054	0.003	<0.01	***
BRD 1st pulls prev day	9.547	1.851	<0.01	***
Distance Traveled	-0.004	0.001	0.01	**
Percent in Feed bunk	10.663	2.440	0.00	***
Percent in Water	-28.798	13.402	0.03	*
Average speed (m/s)	4.979	3.101	0.11	
Calves within 3 m	0.109	0.141	0.44	
Percent 0 calves in 3 m	-0.118	1.966	0.95	
Distance Trav (prev day)	0.0042	0.001	0.01	*
% in Feed (prev day)	-13.691	2.461	0.00	***
% in Water (prev day)	1.039	12.594	0.93	
Speed (prev day)	-10.413	3.631	0.00	**
Calves in 3 m (prev day)	-0.163	0.136	0.23	
% 0 calves in 3 m (prev day)	-7.525	2.055	0.00	***
Max temperature	-0.030	0.017	0.07	.
Min temperature	0.007	0.014	0.59	
Precipitation	0.022	0.005	<0.01	***
Max temp (prev day)	0.058	0.017	<0.01	**
Min temp (prev day)	-0.065	0.014	<0.01	***
Precip (prev day)	-0.005	0.009	0.54	

Several key behavioural and group level variables were significantly associated with the risk of level of BRD first treatments. As days on feed increased, the risk of BRD decreased. The level of treatments the previous day was positively associated with BRD treatments for the current day indicating increased likelihood of pulls on the current day if higher pulls the previous day. As the distance travelled and percent time in water on the current day decreased, the likelihood of having greater number of pulls increased. Sick cattle may be less likely to move around and go to water. The time at the feedbunk actually increased with percent of treatments and this may indicate that sick cattle are hiding in the group at the feedbunk, but not actually consuming feed.

The effects of distance travelled and percent time in the feedbunk illustrated opposite trends when the previous day was evaluated. When cattle spent more time travelling and less time in the feed, it was more likely to have a greater BRD first treatment rate the next day. Additionally, when cattle spent more time in isolation, the first treatment risk was higher the next day.

Weather variables illustrated that higher precipitation was associated with increased 1st BRD treatments. Temperature variables from the previous day played a role with higher maximum temperatures and lower minimum temperatures increasing the risk of first BRD pulls. Each of these scenarios describes the increased weather stress that may have been associated with increased risk for respiratory disease.

4.4 Disease algorithm evaluation

The new algorithms and combinations were initially evaluated on the training dataset consisting of calves deemed in the HLTH or SICK category. These data included all records from the entire trial period (1,852,645 hourly records) for all SICK and HLTH calves. Evaluations were performed on an hourly level within the dataset; therefore, many records from the calves in the “SICK” category may actually have represented behaviour consistent with “HLTH” due to the fact the calves were not ill for the entire feeding period.

All algorithms illustrated a relatively low sensitivity and high specificity which is expected as this analysis was done on the hourly records. When an hourly record was deemed positive it was most likely positive (although the positive predictive value or PPV was relatively low due to the low disease prevalence). In this dataset only 137 calves were deemed SICK and 1486 were HLTH; thus, the hourly records for HLTH calves far outnumbered the records for SICK calves. Calves in the SICK category were also not likely ill the entire period.

Of note in the analysis is the original algorithm displayed a 11.8% Sensitivity. Most of the new algorithms had lower sensitivity but higher specificity than the original. However, several of the newer algorithms illustrated a higher overall diagnostic accuracy. Some algorithms (N2, N8, and Daily_5Se) had higher sensitivity than the original with only a slight drop in specificity. Overall, these algorithms showed great potential in improving the overall accuracy of disease calls in the Australian cattle system. Further evaluations of algorithms will be performed in subsequent live animal trials scheduled for 2020.

5 Discussion

5.1 Comparison of behaviour to carcass outcomes to previous research

The overall level of abnormal pleurisy or lung scores was higher than expected, but the range in previously reported trials for abnormal lung scores is from 36% to 87% (Table 9). Our data align with previous work illustrating a lack of agreement between clinical illness and lung lesions.

Table 9. Summary of previous research comparing clinical illness and lung scores (adapted from 2016 Timset et al.).

	CI Yes; LU Yes	**CI Yes; LU no**	**CI No; LU Yes**	**CI No; LU No**	**total**	**% Lung**	**% clinical**
Gardner et al. (1999)	49	53	38	64	204	43%	50%
Buhman et al. (2000)	37	1	90	18	146	87%	26%
Thompson et al. 2006)	265	196	606	969	2036	43%	23%
Schneider et al. (2009)	121	42	910	592	1665	62%	10%
Leach et al. (2013)	195	60	1395	373	2023	79%	13%
Tennant et al. (2014)	157	29	1344	806	2336	64%	8%
Rezac et al. (2014)	127	157	4591	8316	13191	36%	2%

5.2 Individual animal behaviours and health outcomes

Evaluation of the effect of wellness category on behavioural outcomes was evaluated in a series of multivariable models including factors known to influence behavioural outcomes (hour of the day, days on feed, and breed). Each model included effects to control for lack of independence of the measures due to feedyard, pen, and individual calf. Outcomes from each model can be used to compare behaviours by wellness category across all animals in the study.

5.2.1 Variability in Behavioural measures

These data represented behavioural data collected on 3,114 head in two feedyard environments at multiple time periods. Cattle were fed in typical confined feeding situations; however, a high degree of variability was identified among individual readings and individual calves. Some variables were relatively normally distributed among readings (distance travelled, average speed, average number of calves within 3 meters), while other variables were highly skewed (percent time near feed and water, percent time with 0 calves within 3 meters). Data were aggregated to the calf level and differences among individual calves were identified in this raw analysis. Some calves were more active, spent varied time at water / feed, and differed in social interactions with other cattle. *Results from these raw descriptive analyses indicate that a simplistic threshold to identify sick cattle based on a single threshold may be challenging due to the high calf-to-calf variability.* This is illustrated in the density plots showing the distribution of each behavioural variably by wellness category (SICK, INTR, HLTH) that shows relatively few differences among the overall distribution based on wellness status. *To identify sick cattle based on specific behaviours, other factors that may influence behaviour (such as time of day, days on feed, and breed) should be included in the analyses.*

5.2.2 Activity behavioural measures

Cattle displayed daily activity patterns with certain times of day more likely to be active (higher distance travelled and higher average speed of travel). Active times of day were 6-9 am (likely associated with feeding) and later in the evening (10 pm to 1 am). Cattle were less active during the middle of the day. In distance travelled, few differences were noted among SICK and HLTH calves during active times of day (the most likely time for visual observation). Some differences were noted in average speed during high active times, but this would be challenging to visually observe. If using activity to visually determine wellness status, it might make sense to observe at a time of day when cattle are less active.

Activity patterns also differed by days on feed and this effect was influenced by wellness status. *SICK cattle were more active early in the feeding phase (d 1-2), but less active days 3-6.* In these trials, many of the cattle identified as sick by REDI were identified early in the feeding phase (< d 14). These activity patterns indicate that early indications of behaviour are associated with illness during the feeding period. No differences were noted in activity patterns after the first 28 DOF. Breed also influenced activity patterns with the primary difference being that the Bos Indicus cattle were more active as measured by both distance travelled and average speed. Relatively few differences were noted among other breeds in the study.

5.2.3 Proximity to feed and water behaviours

Feeding and watering behaviours are often listed as key components for identifying cattle afflicted with BRD or other diseases. Typically, the recommendation is to visually observe looking for cattle that do not attend the feed bunk with the group. Watering behaviour is thought to be important, but more difficult to observe as it is a sporadic occurrence. Data from this trial illustrated that both feeding and watering behaviour differed among wellness categories and this effect was modified by both days on feed and time of day.

Cattle in the SICK group spent more time in the water zone days 1-6 compared to HLTH cattle, with relatively few differences after the first week. This could indicate that cattle eventually succumbing to illness were dehydrated early in the feeding phase and spent more time drinking. *Feeding behaviour also differed by days on feed with SICK cattle spending more time at the feedbunk during the first two weeks than cattle in the HLTH category*. This finding is counterintuitive and unexpected but illustrates that observation over the 24 hour period may yield different results than only observing at feeding time.

Time of day also had an impact on feeding and watering behaviour. During the day (8 am to 8 pm) healthy cattle spent more time at the water; however, this trend was reversed during night time hours with sick cattle spending more time at the water. Thus, if water attendance is used to gauge illness status, a simple measure of time at the water to create a threshold may not be accurate in detecting illness. Feeding behaviours also varied by time of day and wellness category with relatively few differences among SICK and HLTH cattle during feeding time (6-9 am). In the late evening hours (10 pm to midnight) sick cattle spent more time at the feedbunk and potentially this was a time of lower social pressures and they could consume feed during this period.

Some breed differences were noted in watering behaviour with Bos Indicus and European cross breeds spending less time in the water zone. The AN, HF, and SH breeds tended to spend more time in the feeding area. Thus, breed may need to be taken into account when evaluating differences in feeding and watering behaviour.

5.2.4 Social parameters

Social parameters are often used in the visual observation of BRD, and observers are trained to identify cattle that spend more time isolated from the group. Cattle are a prey, herd species, and the logic dictates that cattle desire to spend time in the group, not alone. This study used two variables (average calves within 3 meters and percent time 0 calves within 3 meters) to indicate socialization and isolation metrics, respectively.

The average number of calves within 3 meters differed by wellness category and days on feed. *Cattle in the SICK group had a higher average number of calves within 3 meters during the early feeding phase (until approximately day 8), then after day 10, SICK cattle had lower average number of calves within 3 meters compared to healthy category.* Similarly, the isolation index (percent time with 0 calves within 3 meters) illustrated that SICK calves spent less time isolated early in the feeding phase (< d 7) compared to HLTH calves, then after d 9, these findings reversed with SICK cattle spending more time isolated. These findings are logical as early in the disease process cattle may be more likely to hide in the group or spend more time in the herd relative to HLTH cattle. However, after illness has occurred, they may no longer be able to compensate and spend more time isolated. Thus, identifying BRD status early in the feeding phase may be influenced by finding cattle that spend more time in the group which is hard to visually observe. Certainly, after day 8 in this study the SICK cattle spent more time isolated compared to HLTH calves. Time of day had some influence on these findings, but relatively few differences were noted based on hour of the behavioural observations.

Minor differences were noted in the social parameters based on breed. Bos Indicus cattle tended to have a higher average number of calves within 3 meters and spend less time isolated from the group (percent time with 0 calves within 3 meters).

5.3 Pen-level behavioural outcomes

5.3.1 Variability in daily calf pen-level behavioural observations

These data represented behavioural data collected on 12 pens in two feedyards for the first 45-60 days of the feeding period. Cattle were fed in typical confined feeding situations, and some groups of cattle were fed in the same physical pen at different times of year. Observations on daily calf group level revealed significant variability among days and calf groups. *Key behavioural outcomes were normally distributed for the most part when aggregated to the daily calf group level.* The activity variable of average speed in meters per second appeared to have two distinct levels that occurred in relative frequency of higher and lower activity. The activity variable measuring distance travelled showed most of the readings in a relatively tight range; however, individual days had much higher and lower readings than average causing the distribution to have very long tails. These raw descriptive analyses indicate each of the key behavioural variables has a wide range of outcomes over the study period. Thresholds to identify deviations from expected could be implemented, but these may need to be applied to each of the variables.

5.3.2 Density patterns related to wellness status

Analyses were performed evaluating potential differences in distributions based on the daily pen status as classified by the relative percent of first BRD treatments and the day-to-day change in the number of first BRD treatments. Three main outcomes were evaluated: high pull days (defined as > 1%), a high BRD pull delta (> 0.5% increase from previous day), and a low pull delta (< -0.5% from previous day). Using these three categories the overall distributions of behavioural patterns were compared visually. Evaluating high BRD pull days revealed a higher level of variability in many of the key behavioural traits compared to days with lower pulls. This effect was especially apparent on the feeding and watering behaviour and may indicate that days with high BRD pulls do not follow a specific pattern. Social patterns on high pull days indicated cattle tended to have higher number of calves within 3 meters and less time spent alone. *These factors indicate that days with high calf group BRD pulls had some differences from days with lower BRD pulls; yet, the wide variability of specific behavioural variables and overlap of the distribution patterns indicates that setting a single threshold to determine high pull days would be challenging.* Distributions comparing the BRD pull delta were very similar among days with an expected pull delta (or change from previous day) to days where either a higher or lower than expected change in the number of pulls occurred. The distribution of key behavioural variables differed when a high number of BRD pulls were indicating that behavioural monitoring may be useful for delineating days when sick cattle are present in the pen.

5.3.3 Pen-level daily behavioural patterns

A series of multivariable models were created to determine associations of key behavioural variables with daily calf group level covariates of interest including: days on feed, the percent of first BRD pulls on the day of interest, the percent of BRD 1st pulls one day prior, the percent of BRD first pulls averaged over the last 3 days, the deaths per day, and the minimum temperature, maximum temperature, and precipitation on the day of interest, 1 day prior, and 3 days prior. The objective of these analyses is to better understand the relationships among covariates and each of the key behavioural outcomes of interest.

Both distance travelled and average speed represent activity levels within the pen. Cattle displayed daily activity patterns with certain times of day more likely to be active (higher distance travelled and higher average speed of travel). Both activity variables showed a decrease over time (measured by DOF), and this likely indicated a decrease in pen level activity later in the feeding period when cattle would be acclimatized to the social structure and the main disease risk has passed. *Both activity variables were negatively associated with the 3-day average of the number of BRD 1st pulls: the higher the 3-day average of BRD 1st pulls, the lower the pen activity level.* A clear decrease in calf group level activity associated with BRD challenge was present in the data; however, it should be noted that the actual change may be challenging to identify visually as the actual drop in activity was numerically small. For example, if the 3-day average of BRD first pulls moved from 0 to 2% (a significant movement indicating pen-level disease challenge), the average distance travelled moved from ~205 to 185 meters/hr which would be difficult for an observer to visually identify. Activity changes were also associated with weather, but relatively few associations were identified in this area.

Previous work has shown differences in feeding and watering behaviour comparing diseased to healthy animals. This analysis evaluated potential differences at the calf group level and illustrated daily calf group feeding and watering times were negatively associated with daily BRD pulls. *Both time in the water and feed decreased as the number of first treatments for BRD increased.* The change in calf group level feeding and watering behaviour could be useful to identify specific days when the BRD treatment rate might be higher. Watering behaviour was also influenced by weather variables with a higher percent time spent at the water when minimum and maximum temperature were higher and a lower time at the water when the precipitation was higher. The percent time the calf group spent in feed also decreased as maximum temperature increased. Calf group level daily feeding and watering behaviour was associated with several factors of interest including the number of first treatments for BRD.

Social parameters are often used in the visual observation of BRD, and observers are trained to identify cattle that spend more time isolated from the group. Cattle are a prey, herd species, and the logic dictates that cattle desire to spend time in the group, not alone. Social parameters have rarely been evaluated on a daily calf group level to determine population changes over the feeding period. Both the social index (average number of calves within 3 meters) and the isolation index (percent time spent with zero calves within 3 meters) were associated with days on feed. *Cattle spent more time in the group early in the feeding phase and more time in isolation as the days on feed increased.* This effect may be due to the acclimatization to the pen social structure and feeding environment as the period progressed. Cattle tend to spend more time in the group when stressful events occur, and early in the feeding phase these groups of commingled calves would have been going through a social transmission and most of the BRD cases were early in the feeding phase. Only the social index was associated with BRD and illustrated that calves had a greater number of average calves within 3 meters when the BRD treatment rate was higher on the previous day. Weather also had some influence on social parameters.

5.3.4 Pen-level associations of behaviour, weather, and health status with daily percent of first BRD treatments

A statistical model was created to evaluate the daily proportion of BRD treatments and potential associations with behavioural (distance travelled, speed, percent time in water, percent time in feed, average number of calves within 3 meters, percent time with zero calves in 3 meters), health (BRD first pulls the previous day), and weather (maximum temperature, minimum temperature, precipitation). The behavioural and weather variables included the calf group level parameters for the current day of interest and the previous day. The goal of the model was to identify potential determinants of higher BRD treatment daily risk. Several calf group level factors were significantly associated with risk of higher first BRD treatment. As days on feed increased BRD risk was less likely, and the greater number of treatments the previous day was associated with a greater number of treatments on the current day. Interesting effects were observed when comparing the previous and current day on behavioural variables, for example, days at high risk for BRD pulls were associated with lower distance travelled, but the previous day was associated with higher distance travelled. A similar inverse impact was observed related to percent time at the feedbunk. *These findings* *illustrate that daily calf group level behavioural variables were associated with group level BRD treatment risk, and the effects were complex and reliant on multiple factors including differences over time.* The risk of calf group level BRD treatment was also associated with weather variables. More data is needed to determine potential methods to combine these data into a more effective method for determining high risk days for BRD. *The number of factors associated with BRD risk indicates the complexity of creating a calf group level wellness threshold and that reliant on a single factor may not represent the entirety of the picture of wellness for the group.*

5.4 Comparisons of optimized algorithms

Several new algorithms were identified offering similar diagnostic capabilities to previous algorithms. Some of the new algorithms offered marginal improvement in diagnostic ability; however, attempts to increase sensitivity often resulted in a higher number of overall disease calls. The analyses illustrated variable expected diagnostic performance (positive and negative predictive values) based on expected prevalence within the population. This result lends credence to the further idea that a variety of algorithms may need to be employed during the feeding phase based on the expected prevalence at the time (higher early in the feeding period and lower later in the feeding period). This is now possible with the spectrum of algorithms presented.

Further work needs to be done to refine the timing of algorithm calls and offer improvements in sensitivity without harming the specificity. When considering hourly behaviour records, the true prevalence of illness on an hourly basis is very low. For example, in the cattle classified as SICK 141,089 hourly records were recorded; however, when this is limited to only 4 days prior and 3 days post BRD only 7,911 (5%) records are left. When considering the entire dataset, the potential number of sick hours represents only 0.2% of all records indicating a very low prevalence. The fact that the algorithms perform well on specificity is very important and each of the new algorithms performed well in this category. To increase sensitivity, more information is needed on the specific timing of disease onset with confirmation of disease timing based on a gold standard at the time of clinical signs.

Optimizing algorithm classification accuracy is strictly dependent on comparing predictions to known outcomes. The previous trial provided a novel dataset incorporating hourly individual behavioural data over the entire feeding period combined with individual animal performance and pulmonary scores at harvest. When these data were combined with treatment history and disease related deaths, the cattle can be classified into SICK or HLTH categories. One caveat with this approach is there was a subset of cattle classified as intermediate (INTR) where the health status through the feeding period was uncertain. Examples include cattle that were treated for BRD but had minimal to no pulmonary lesions. These cattle may have been truly ill, yet early intervention limited the scope of pulmonary lesions. Additionally, cattle never treated, yet having mild lung lesions, were included in the INTR category as they may have had lesions present prior to the trial (no illness during the trial) or had a minor illness that did not require treatment.

The classification of the HLTH cattle provides a solid known reference point as cattle that were never treated during the period and had no pulmonary lesions can be considered to have been healthy throughout the trial. In the diseased cattle (presence of pulmonary lesions at slaughter and/or multiple treatments), we can confidently assert they were sick during the trial. The challenge with interpreting behavioural data from the SICK calves is that although they were ill at some point during the trial, it is unlikely they were ill throughout the trial period. Illness due to BRD is often transient and while behavioural data were recorded hourly through the period, the SICK cattle were likely only truly ill during a shorter period of time. This makes classification of all hourly records from a SICK calf challenging as we cannot determine exactly when the calf was ill.

6 Conclusions/recommendations

6.1 Association of behavioural and pulmonary outcomes

This analysis demonstrated a significant correlation between consolidation and pleurisy scores and carcass outcomes. The relationship is meaningful as increased (more severe) lung scores resulted in decreased performance. This analysis shows that cattle could be partitioned using lung data and management history into three distinct groups: known healthy (never treated, minimal lung scores), known diseased (treated, died, or lung / pleurisy score of 3 or NS), or uncertain outcomes. The known healthy and diseased represent sufficient data to achieve the objectives in the proposed project to evaluate the relationships of behavioural patterns and health outcomes.

6.2 Individual behavioural patterns and wellness outcomes

In aggregate these analyses illustrated several key behavioural parameters are associated with wellness category. The wellness categories in this study were defined as known SICK or HLTH based on lung scores, treatment history, and health outcomes. Using these mutually exclusive case definitions allowed evaluation of association of behaviours and known health status. The behavioural data displayed large degrees of variability; however, when multivariable models were applied, several key associations with wellness category were identified.

Activity, proximity to feed and water, and social parameters were associated with wellness categories, but many of these effects were modified by time of day or days on feed. Behavioural findings confirmed dogma in identifying illness including that sick calves are less active, spend more time by themselves, and have less feedbunk attendance at feeding time. However, these findings do not tell the whole story as the activity of SICK calves differs by time of day. SICK calves also spend more time at the feedbunk at certain times of day and watering behaviour differs early in the feeding phase. Social parameters provided interesting insight to cattle behaviour with a differentiation early in the feeding phase (SICK cattle more social) to after d 10 on feed when SICK cattle became less social. These behavioural observations provide information to help inform the process of determining which cattle are suffering from BRD.

6.3 Pen-level behavioural patterns and wellness outcomes

In aggregate these analyses illustrated that daily calf group level behavioural and weather parameters were associated with the risk of first BRD treatments in the calf group. Behavioural parameters displayed variability through the feeding phase and this variability was influenced by the risk for BRD and changes in weather. Evaluating individual parameters without full information (e.g. days on feed, weather) may be misleading regarding to associating specific changes in activity or behaviour with BRD risk. However, when a multivariable model was generated, several key associations with wellness categories were identified.

Previous work has shown associations of key behavioural parameters with wellness changes on the individual calf level, and this study illustrates that calf group level effects are also associated with disease status. Cattle are housed in a group environment and understanding changes in population-level behaviour can be useful for identifying groups of cattle that need further observation or intervention.

6.4 Diagnostic algorithm comparisons

In aggregate, these analyses illustrated that the series of new algorithms are comparable to previous algorithms with improvements in some areas. This is a valuable finding as it displays the robustness of the REDI algorithms and ability to distinguish key differences based on behaviour. Two key findings include the determination that algorithm diagnostic performance varies based on expected prevalence and the new ability to have multiple algorithms that can be deployed at varied times. The new series of algorithms provides additional options that could be evaluated in individual feeding operations to determine the best fit for each operation. While more research is needed to continue to improve the system, this project illustrated the overall performance of REDI algorithms to be suitable for Australian feeding systems.