Respiratory Disease Monitoring in Feedlot Cattle

by

Barbara Wolfger

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

VETERINARY MEDICAL SCIENCES GRADUATE PROGRAM
CALGARY, ALBERTA

April, 2015

© Barbara Wolfger 2015
Abstract

Bovine respiratory disease (BRD) remains the most significant disease complex in the feedlot industry worldwide. Approximately 16% of the incoming cattle population develops BRD during the feeding period. Commonly, trained feedlot personnel visually observe cattle in the home pen and decide on treatment if necessary. However, inaccurate and late diagnosis contributes to economic losses associated with this important disease. The overall aim of this thesis was to explore methods to increase accuracy and improve timing of BRD detection in feedlots. Research presented in this thesis focused on using automatic recording system for individual feeding behaviour, evaluated 2 alternative automated behaviour monitoring systems, identified the economic value of using automated behaviour recording systems and summarized current methods to improve accuracy of visual detection, timing of identification and prognostic methods for unfavourable BRD outcome. Chapter two demonstrated that continuous monitoring of feeding behaviour with individual feedbunks identified sick steers up to 7 days before visual signs of BRD appeared. Increased average meal-size, meal-time, time between meals and frequency of meals were associated with decreased BRD hazard. Two automatic recording systems for feeding but also other behaviour were evaluated in chapter 3 of this thesis. An ear-motion detector was highly sensitive and moderately specific in feeding time monitoring, but was highly specific with low sensitivity for rumination recording. Conversely, a leg-attached accelerometer accurately measured bunk attendance, bunk visit frequency as well as lying time. Chapter 4 demonstrated that the costs of individual feedbunks as used in chapter 2 did not outweigh the benefits of earlier and more efficient treatment. To be cost effective for BRD detection the per
animal costs of the system would have to be < CAD 4, unless the true BRD incidence exceeded 47%. Finally, chapter 5 demonstrated that automated monitoring systems have been implemented successfully to detect BRD. Specifically, feeding behaviour and temperature monitoring could be used for early identification of BRD affected cattle.
Preface

The work presented within this thesis benefitted from a team effort. The thesis consists of four submitted manuscripts of which two have been accepted for publication and two are currently under revision. The discussion part of the thesis is a review that will be submitted within the upcoming weeks. In all chapters, Barbara Wolfger was involved in the data collection, management and analysis, and writing final reports to the funding agency. This was done under guidance of her supervisor, Karin Orsel. All co-authors provided their expertise and critically reviewed the manuscripts. In accordance with the University of Calgary’s copyright guidelines, written permission for reproduction of the full articles was obtained from all co-authors and publishers.


Acknowledgements

I would like to thank my supervisor, Karin Orsel, for guiding me through my PhD. Thank you for your patience, and for encouraging me to pursue my academic career. You were a great supervisor, teacher, mentor and friend during the past 4 years and I cannot even thank you enough for your support! I also want to take the opportunity to thank my committee members: Drs. Herman Barkema, Michel Levy, Ed Pajor and Karen Schwartzkopf-Genswein. It was great to know that I could always knock on your doors or call when I needed advice. Thank you for supporting but also challenging me when needed! Thank you to Dr. John Kastelic for your assistance in scientific writing.

Thank you, Maarten van den Bosch, for your enthusiasm and valuable help during the hard field season in 2010 and Uliana Kanevets for helping to process the samples in the lab.

Thank you Drs. Alessandro Massolo, Kent Hecker and Carl Ribble for hiring me as a teaching assistant and sparking my passion for teaching.

I would like to also thank my friends and colleagues Taya Forde, Laura Solano and Christina Ahlstrom for stimulating discussions of projects, improving presentations, critical appraisals and brainstorming ideas. Thank you to all the people I met throughout the years that I can call my international friends. You all contributed to a fantastic experience in Calgary. Thank you for caring so much! Without you my PhD would have only been half as much fun!

Finally, I would like to thank my (quickly growing) family that encouraged me in my decision to go abroad and continue studying.
I would like to acknowledge the Alberta Funding Consortium, University of Calgary Eyes High and the University of Calgary for their financial assistance throughout the years.
To Robert, my partner in crime! May the adventures continue...
Table of Contents

Abstract ............................................................................................................................... ii
Preface ............................................................................................................................... iv
Acknowledgements .......................................................................................................... vi
Table of Contents .............................................................................................................. ix
List of Figures and Illustrations ...................................................................................... xiv
List of Symbols, Abbreviations and Nomenclature ......................................................... xv

CHAPTER ONE: GENERAL INTRODUCTION ............................................................. 1
  1.1 Definition and pathogenesis of bovine respiratory disease ....................................... 2
  1.2 Detection of BRD ..................................................................................................... 3
    1.2.1 Traditional detection in commercial feedlot operations ................................... 3
    1.2.2 Apparent prevalence, incidence and mortality ................................................. 5
    1.2.3 Evidence for lack of diagnostic accuracy ......................................................... 6
    1.2.4 Consequences of low detection accuracy ......................................................... 7
  1.3 Use of behaviour recording systems for disease detection ....................................... 8
    1.3.1 Feeding behaviour ............................................................................................ 9
    1.3.2 Activity monitoring ........................................................................................ 10
    1.3.3 Cost of automated monitoring systems .......................................................... 11
  1.4 Project rationale and objectives .............................................................................. 12

CHAPTER TWO: FEEDING BEHAVIOUR AS AN EARLY PREDICTOR OF BOVINE RESPIRATORY DISEASE IN NORTH AMERICAN FEEDLOT SYSTEMS ................................................................................................................ 14
  2.1 Abstract ................................................................................................................... 15
  2.2 Introduction ............................................................................................................. 16
  2.3 Materials and Methods ............................................................................................ 17
    2.3.1 Study design, animals and housing................................................................. 17
    2.3.2 Case definition and treatment ......................................................................... 18
    2.3.3 Laboratory analyses ........................................................................................ 20
    2.3.4 Feeding data collection ................................................................................... 21
    2.3.5 Statistical analysis ........................................................................................... 21
  2.4 Results ..................................................................................................................... 24
    2.4.1 Laboratory results ........................................................................................... 24
    2.4.2 Case identification .......................................................................................... 24
  2.5 Discussion ............................................................................................................... 26

CHAPTER THREE: EXPLORING ALTERNATIVE METHODS OF BRD DETECTION ........................................................................................................... 41
  3.1 Accuracy of an ear tag-attached accelerometer to monitor rumination and feeding behaviour in feedlot cattle .......................................................... 42
    3.1.1 Abstract ........................................................................................................... 42
    3.1.2 Introduction .................................................................................................... 43
    3.1.3 Material and Methods ..................................................................................... 44
    3.1.4 Results ............................................................................................................ 47
    3.1.5 Discussion ....................................................................................................... 47
3.2 Evaluation of a system for monitoring individual feeding behaviour and activity in beef cattle

3.2.1 Abstract
3.2.2 Introduction
3.2.3 Materials and Methods
3.2.4 Results
3.2.5 Discussion

CHAPTER FOUR: EVALUATING THE COST IMPLICATIONS OF A RADIO FREQUENCY IDENTIFICATION FEEDING SYSTEM FOR EARLY DETECTION OF BOVINE RESPIRATORY DISEASE IN FEEDLOT CATTLE

4.1 Abstract
4.2 Introduction
4.3 Methods
4.3.1 BRD detection methods
4.3.2 Estimating true incidence
4.3.3 Design
4.3.4 Costs
4.3.5 Revenue
4.3.6 Comparators
4.3.7 Model structure
4.3.8 Uncertainty and Variability
4.3.9 Scenario analyses based on cattle type
4.3.10 Assumptions and applications
4.3.11 Model validation
4.4 Results
4.4.1 Uncertainty analysis
4.5 Discussion
4.5.1 Conclusions

CHAPTER FIVE: REVIEW: RECENT ADVANCES IN BOVINE RESPIRATORY DISEASE CONFIRMATION, EARLY DETECTION AND PREDICTION OF UNFAVORABLE OUTCOME IN FEEDLOT CATTLE

5.1 Abstract
5.2 Introduction
5.3 Methods
5.3.1 Definitions for the search
5.3.2 Criteria for considering studies
5.3.3 Search strategy
5.3.4 Selection of studies
5.4 Results and Discussion
5.4.1 Excluded studies
5.4.2 Part 1: Confirmatory diagnostics
5.4.2.1 White blood cell count
5.4.2.2 Acute Phase Proteins
5.4.2.3 Detection of BRD pathogens
List of Tables

Table 2.1: Descriptive statistics of feeding behaviour variables for steers between d 7 and d 1 before pulling and steers that were visually healthy during the entire 35 d period ................................................................. 32

Table 2.2: Complete and differential blood cell count and acute phase proteins at first pull and percentage of steers greater or lower than the reference interval (RI) for haptoglobin-positive cattle with a rectal temperature $\geq 40.0^\circ C$ and $\geq 2$ clinical signs of bovine respiratory disease (BRD) (n = 66) .................................................. 34

Table 2.3: Hazard Ratios for variables included in the final models to predict visual identification of bovine respiratory disease (BRD) in the first 35 d after arrival to the feedlot, with (Y) and without (N) feed intake measures; modeled between 1 and 7 d before visual identification (d -1 to d -7). The analyses included polynomial models of days on feed ................................. 35

Table 3.1: Observational times in min (% of total) per steer ........................................... 51

Table 3.2: Comparison between observed (row) feeding, rumination and other behaviour (others) and unadjusted accelerometer-recorded (SensOor, Agis Automatisering, Harmelen, The Netherlands) behaviour (column) per min (% of observed behaviour how it was recorded by accelerometer) ........................................ 52

Table 3.3: Test characteristics (95% CI) of an ear tag-attached accelerometer (SensOor, Agis Automatisering BV, Harmelen, The Netherlands) to monitor feeding and rumination in feedlot cattle adjusted for clustering within steer ............... 53

Table 3.4: Concordance correlation coefficient (CCC) adjusted for repeated longitudinal measures comparing FEDO (Rosh, Pina, Israel) and 1) live observations (OBS), 2) HOBO, and 3) video observations. ........................................... 64

Table 4.1: Probability estimates for steer calves at high-risk of Bovine Respiratory Disease (baseline scenario), extracted from USDA NAHMS Feedlot 2011 study (USDA, 2013a) as calculated with a relative risk of retreatment (0.60) and a relative risk of death in treated steers (0.66) in the automated recording system (ARS) ....................................................................................................................... 86

Table 4.2: Production costs, revenues (CAD) and cohort characteristics of a feedlot cattle population at high-risk for bovine respiratory disease (20% treatment rate) in Canada and the United States (US) .................................................. 87

Table 4.3: Variables that differed from the baseline analysis for cattle at low risk of bovine respiratory disease comparing pen-checking and an automated recording system (ARS). Probabilities extracted from USDA NAHMS Feedlot 2011 study (pen-checking column) and calculated when ARS with lower retreatment and death losses after first treatment was used. Days on feed were extracted from the Veterinary Agri-Health (VAHS) database, ADG from Cernicchiaro et al. (2013). 89
Table 4.4: Input sensitivity (Se) and specificity (Sp) point estimates (%) for detecting bovine respiratory disease in percentage using priors in the Bayesian software WinBUGS (Lunn et al., 2000) with > 5% lung consolidation (Amrine et al., 2013) and extracted from literature to account for uncertainty through scenario analysis..................................................................................................................... 91

Table 4.5: Difference in cost between a BRD monitoring strategy involving pen-checking and an automated recording system (ARS), including the impact of varying sensitivity and specificity..................................................................................................................... 92

Table 5.1: Search terms to extract manuscripts of interest. Rows were combined with AND ......................................................................................................................................................... 114

Table 5.2: Acute phase protein changes during bovine respiratory disease (BRD) compared to controls (C)......................................................................................................................................................... 115
List of Figures and Illustrations

Figure 2.1: Selection criteria and sample sizes for cases and controls. .......................... 37

Figure 2.2: First visual detection a) over the entire feeding period, and b) within 35 d after arrival. ................................................................................................................................. 38

Figure 2.3: Demonstration of data collection over observation time with an example of a pulling event on day 12. ........................................................................................................ 39

Figure 2.4: Percent of case (solid lines) and control (dashed lines) steers detected by BRD hazard model using time variables only (black lines, squares) and including intake variables (gray lines, triangle). ................................................................................... 40

Figure 3.1: Number of minutes that individual steers spent a) feeding and b) ruminating during 1 h recorded by observers (y) and the accelerometer (x). Note that individual steers are represented in various shapes and colors ........................................... 54

Figure 3.2: FEDO logger recognizes electromagnetic field transmitted by antenna........... 65

Figure 3.3: Difference between FEDO (Rosh, Pina, Israel) and a) feeding behaviour recorded with live observations; b) lying time during 6-h periods recorded by validated accelerometers (HOBO); and c) number of steps counted with video observations in 6-min observations .................................................................................. 67

Figure 4.1: Decision tree to assess the difference in net-benefit between automated recording systems and pen-checking for detection of BRD in feedlot cattle. ................. 93

Figure 4.2: Changes in net-benefit with variability in variables described in Table 4.1 if an automated feeding behaviour recording system (ARS) is used in comparison to pen-checker detection (above 0 means in favor of pen-checker detection). The right vertical line represents the baseline scenario with a net-benefit difference of CAD 9.61 per steer and the bars represent a change between the net-benefit differences when single variables are changed. Bars crossing zero to the left illustrate economic dominance of ARS (left vertical line)................................................................. 94

Figure 5.1: Stepwise exclusion and exclusion of literature evaluated for inclusion in the rapid systematic review (Moher et al., 2009) ................................................................................... 117

Figure 5.2: Clinical and behavioural signs change after viral and bacterial infection; data adapted from (Aich et al, 2009; Hanzlicek et al, 2010; Rose-Dye et al, 2011; Theurer et al., 2013) ...................................................................................... 118
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRD</td>
<td>Bovine respiratory disease</td>
</tr>
<tr>
<td>s</td>
<td>Seconds</td>
</tr>
<tr>
<td>min</td>
<td>Minutes</td>
</tr>
<tr>
<td>h</td>
<td>Hour(s)</td>
</tr>
<tr>
<td>d</td>
<td>Day(s)</td>
</tr>
<tr>
<td>wk</td>
<td>Week(s)</td>
</tr>
<tr>
<td>mo</td>
<td>Month(s)</td>
</tr>
<tr>
<td>y</td>
<td>Year</td>
</tr>
<tr>
<td>DOF</td>
<td>Days on feed</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio frequency identification</td>
</tr>
<tr>
<td>ADG</td>
<td>Average daily gain</td>
</tr>
<tr>
<td>APP</td>
<td>Acute phase proteins</td>
</tr>
<tr>
<td>HP</td>
<td>Haptoglobin</td>
</tr>
<tr>
<td>SAA</td>
<td>Serum amyloid A</td>
</tr>
<tr>
<td>s.c.</td>
<td>Subcutaneous</td>
</tr>
<tr>
<td>CBC</td>
<td>Complete blood cell count</td>
</tr>
<tr>
<td>TP</td>
<td>Total protein</td>
</tr>
<tr>
<td>FB</td>
<td>Fibrinogen</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of variation</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>BW</td>
<td>Bodyweight</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>ARS</td>
<td>Automated recording system</td>
</tr>
<tr>
<td>CAD</td>
<td>Canadian dollar</td>
</tr>
<tr>
<td>USD</td>
<td>US dollar</td>
</tr>
<tr>
<td>n</td>
<td>Study population</td>
</tr>
<tr>
<td>g</td>
<td>Gram</td>
</tr>
<tr>
<td>kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>IQR</td>
<td>Inter-quartile range</td>
</tr>
<tr>
<td>r</td>
<td>Coefficient of correlation</td>
</tr>
<tr>
<td>BAL</td>
<td>Bronchoalveolar lavage</td>
</tr>
<tr>
<td>pi</td>
<td>Post infection</td>
</tr>
<tr>
<td>PI</td>
<td>Persistently infected</td>
</tr>
<tr>
<td>BVDV</td>
<td>Bovine viral diarrhea virus</td>
</tr>
<tr>
<td>BHV-1</td>
<td>Bovine herpes virus</td>
</tr>
<tr>
<td>IRT</td>
<td>Infrared thermography</td>
</tr>
</tbody>
</table>
Chapter One: GENERAL INTRODUCTION
1.1 Definition and pathogenesis of bovine respiratory disease

Bovine Respiratory Disease (BRD) in feedlot cattle is a multifactorial disease complex including infection with a wide range of conditionally or obligatory pathogenic viruses and bacteria and exposure to stressors (Duff and Galyean, 2007). Calves entering a feedlot are exposed to several stressors around the time of entry. In several studies, processing at arrival (e.g. vaccination, implants, anthelmintic treatment, castration, dehorning, and abortifacients), and weaning right before shipping increased BRD susceptibility (Taylor et al., 2010). Stressors negatively impact the immune response and predispose to bacterial-induced pathology in the lower respiratory tract (Mosier, 2014). In particular, maternal separation and weaning, comingling and market stress reduced health after arrival (Step et al., 2008). A recent study also suggested a positive association between BRD incidence and distance from sale barn across all seasons (Cernicchiaro et al., 2012b). Additionally, environmental factors, specifically wind speed, wind chill temperature and temperature change, have been reported to significantly increase daily BRD incidence in feedlots. From the host and management perspectives, the same study reported month and year of arrival, days on feed (DOF), arrival weight, sex, size of the cohort (lot arriving at the same time) and BRD risk code on arrival (high versus low) as significant predictors of BRD treatment within the first 45 DOF (Cernicchiaro et al., 2012a).

Respiratory viruses including bovine herpes virus-1 (BHV-1), parainfluenza virus-3 (PI-3), bovine respiratory syncytial virus (BRSV) and bovine viral diarrhea virus
(BVDV) are recognized as major pathogens contributing to BRD (Mosier, 2014). The involvement of these viruses can cause damage to the respiratory mucosa, modify the immune system or act synergistically in co-infections with other pathogens (Jones and Chowdhury, 2010; Ridpath, 2010). The most important bacterial pathogens are *Mannheimia haemolytica, Pasteurella multocida, Histophilus somnus* and *Mycoplasma bovis* (Griffin et al., 2010). Some BRD-associated bacteria (i.e. *P. multocida* and *H. somnus*) can co-exist with the healthy host in commensal biofilms (Elswaifi et al., 2012). A biofilm protects bacteria against host defences, toxins and antimicrobials. However, a change in the biofilm microenvironment, including nutrient concentration, lack of oxygen, temperature changes or stressors can trigger dispersal of free-living forms from the biofilm (McDougald et al., 2012).

Both, *M. haemolytica* and *P. multocida* were isolated in nasal swabs and bronchoalveolar lavages (BAL) from clinically healthy calves as well as BRD cases (Allen et al., 1991). However, *M. haemolytica* was more commonly isolated in calves at treatment compared to time of arrival or control calves (Taylor et al., 2014). Stressors, viral infection and cold air stimulate nasal colonization with bacteria, which subsequently challenges the lung by inhalation of infected droplets (Caswell, 2014).

### 1.2 Detection of BRD

#### 1.2.1 Traditional detection in commercial feedlot operations

Cattle are prey animals and mask clinical signs of illness or show them late in the disease progress. Behaviour, fever and appearance of domestic animals have been used and described for health evaluation soon after domestication began (Weary et al., 2009).
The classical image of a depressed, lethargic animal with little interest in food or water accompanies fever episodes (Hart, 1988). From onset of fever, however, it can take days until the first clinical signs of BRD are detectable in cattle. Nasal discharge, as one of the first symptoms, appeared approximately 1 d after hyperthermia. Abnormal pulmonary sounds, depression, cough and ocular discharge consecutively appeared between 1 and approximately 5 d after hyperthermia in naturally occurring BRD (Timsit et al., 2011a).

Caregivers are trained to identify common clinical signs of BRD in the pen (pen-checking), including depression, loss of appetite, and change of respiratory character and rate to subsequently evaluate disease status based on temperature in the treatment chute (Griffin, 2014). Other clinical signs of BRD can be cough, lack of rumen fill (as a sign of loss of appetite), nasal and ocular discharge (Montgomery et al., 2009). Routinely, pen-checking is performed once per day but can be done more frequently during the first critical weeks after arrival (USDA, 2013b).

Although subjective scoring might identify large changes in behavioural activities, it might not be sufficiently refined to detect subtle changes. Clinical illness scoring with rectal temperature confirmation has low sensitivity (62%) and specificity (63%) (White and Renter, 2009). Additionally, the late appearance of clinical signs may hamper high treatment efficacy and increase case fatality (Ferran et al., 2011) and lower case fatality (Janzen et al., 1984) is hampered by late appearance of clinical signs. Alternative approaches to detect BRD therefore will be explored in this dissertation to increase detection accuracy by means of objective evaluation methods and earlier detection relative to pen-checking.
1.2.2 Apparent prevalence, incidence and mortality

In an attempt to estimate BRD prevalence and incidence, treatment records of feedlots using pen-checking and clinical evaluation are frequently used. However, such methods are prone to subjectivity, with large variability among evaluators in sensitivity and specificity of detection based on clinical signs (Amrine et al., 2013). Diagnosis of BRD in feedlots is therefore challenging and treatment records only provide apparent prevalence estimates.

A feedlot study performed by the US Department of Agriculture (USDA) surveyed 403 feedlot operations in 13 states with feedlots. Overall, according to feedlot responses 16% of cattle were affected by BRD after arrival to the feedlot (USDA, 2013a). In a comparable study in 1999, 14% of all placements were treated for BRD (USDA, 2000). Therefore, despite efforts to reduce morbidity and mortality of BRD with metaphylactic and vaccine protocols in the last decades, a substantial proportion of cattle still require treatment for BRD.

The risk to develop BRD, nevertheless, depends on several factors and is highly variable. Lightweight cattle placed on feedlots with one-time capacities of > 8,000 head were at particularly high risk (22%) during the feeding period (USDA, 2013a), and annual incidence of BRD varied significantly across years in single feedlots (5 to 44%; Snowder et al., 2006).

Respiratory disease also remains the number one cause of death in feedlots. The total mortality rate in 121 feedlots in the US between 1994 and 1999 was 13 cattle/1000, with 57% attributed to respiratory disease (Loneragan et al., 2001). In a Canadian study the predominant disease identified in necropsy of cattle dying within 60 DOF was
pneumonia (Gagea et al., 2006). Similarly, in a study including 237 dead cattle from a single feedlot in Oklahoma, over half of all deaths were attributed to BRD (Fulton et al., 2009).

The high number of cattle treated and dying from BRD has serious economic consequences, as cattle treated during the feeding period are less profitable and death is a total loss. The per-head net-return (slaughter value – costs) decreases with increasing number of BRD treatments (Cernicchiaro et al., 2013). Ample evidence of the effect of BRD treatment on average daily gain (ADG) reduction during the feeding period has been provided (Gardner et al., 1999; Thompson et al., 2006; Schneider et al., 2009).

Economic losses due to mortality include purchase price, cost of feed, processing and medical costs, disposal costs and costs of labour and interest on invested money (Loneragan et al., 2001).

Economic losses associated with BRD could be reduced by prevention, and earlier intervention, which reduces relapses (Ferran et al., 2011) and mortality associated with BRD (Janzen et al., 1984).

1.2.3 Evidence for lack of diagnostic accuracy

Post-mortem evaluations identify cattle with lung lesions, an indicator of previous respiratory disease. Lung lesion scoring at slaughter was more accurate in identifying BRD occurrence during the finishing phase compared to the predominantly used clinical illness scoring (White and Renter, 2009). A recent study including > 19,000 head at slaughter from 6 commercial feedlots in the mid-west US identified 23 and 10% of cattle with mild and severe lung lesions, respectively, which was not necessarily reflected in
treatment records (Rezac et al., 2014). Earlier studies drew similar conclusions; many cattle that were never treated for BRD during the finishing phase had either active (9%) or inactive lung lesions (28%) at slaughter (Gardner et al., 1999). Also, 70% of cattle with lung lesions were never treated during the feeding period in a South-African study (Thompson et al., 2006).

The discrepancy between treatment records and post-mortem examinations therefore highlights the lack of accuracy of pen-checking. Clearly, more accurate diagnostic methods would decrease the number of missed cases.

1.2.4 Consequences of low detection accuracy

The inaccuracy of BRD diagnosis leads to a substantial proportion of missed cases, or conversely to situations wherein healthy cattle are unnecessarily treated. This not only has important economic and welfare consequences, but also implications regarding prudent antimicrobial use.

Firstly, economic disadvantages arise from misclassification. Treatment costs are currently estimated at approximately USD 24 per BRD case (USDA, 2013c). Low sensitivity and specificity result in low positive predictive value (depending on true prevalence), which leads to a high proportion of cattle treated unnecessarily. Concurrently, subclinical respiratory disease (not detected using pen-checking but with lung lesions at slaughter) reduces feedlot performance and could eventually lead to death of the animal without prior detection. Cattle at slaughter with severe lung lesions had ADG of 0.07 kg and lower hot carcass weight of 7 kg (Rezac et al., 2014). Similarly, cattle with respiratory lesions (active and inactive) had significantly lower ADG (Gardner
et al., 1999), whereas another study reported no differences in cattle with no or inactive lesions, although there was a significant difference in cattle with active bronchial lymph nodes (Schneider et al., 2009). Furthermore, when necropsies were performed on all deaths in one feedlot, some animals with lung lesions were not detected and treated for BRD prior to death (Fulton et al., 2009).

A second effect of low detection accuracy is the resulting misuse of antimicrobials. The global emergence of antimicrobial resistance in human medicine has led to developments and guidelines on antimicrobial use in veterinary medicine and production animal health (EFSA, 2012; WHO, 2012). Both of these international organizations endorsed the prudent use of antimicrobials in the food production industry.

The third effect of low diagnostic accuracy is the reduced animal welfare associated with compromised health. Using the 5 freedoms suggested in the Brambell report (1965), the core concepts of animal welfare are based on 4 parts: feeding, housing, health and behaviour (Botreau et al., 2007). Cattle that have not been detected as BRD cases during the feeding period might not show suffering but could still experience pain and distress. Therefore, more accurate diagnostic methods are therefore needed to avoid economic losses and reduced animal welfare due to overtreatment and missed cases.

1.3 Use of behaviour recording systems for disease detection

Progressive livestock production is steadily moving towards the use of electronic identification and measuring systems (Brehme et al., 2008). This might be partly attributed to fewer qualified personnel available in the agricultural sector (Fisher and
Knutson, 2013), but also aims to support decision-making and improving farm profitability and productivity. An example of improved profitability with technical applications specific to feedlots is the use of individual feeding behaviour recording systems to determine feed efficiency (Basarab et al., 2003).

Lack of detection accuracy and need for improved early detection has prompted investigation of automated monitoring systems for disease detection. In principle, automated monitoring systems enable non-stop and objective recording of behaviour (Theurer et al., 2013a; Weary et al., 2009). Although not very specific to a single disease, previous studies have indicated that automated body temperature monitoring (Schaefer et al., 2007; Timsit et al., 2011a) and records of automated feeding and watering behaviour monitoring systems can differentiate between sick and healthy cattle (Sowell et al., 1999; Quimby et al., 2001).

1.3.1 Feeding behaviour

As described previously, anorexia is one of the signs accompanying general malaise (Hart, 1988), but also of respiratory disease in particular (Apley, 2006). Thus, monitoring feeding time, intake and frequency have been explored for detection of BRD. Technologies that have been used are either based on individual feed bunks that recognize unique feedlot identification (Sowell et al., 1999; Buhman et al., 2000; Quimby et al., 2001) or location monitoring systems, providing a proxy of feeding time (Theurer et al., 2013b). In an infection trial it was apparent that 1 day after infection, cattle spent less time at the grain bunk, and between the day of infection and 2 d later, less time at the hay feeder (Theurer et al., 2013b). Significant differences between sick and healthy cattle
in naturally occurring BRD were reported during the first weeks after arrival at the feedlot (Sowell et al., 1999; Buhman et al., 2000). Changes in feeding time relative to the timing of visual detection have been retrospectively used to predict cattle destined to become sick, on average 4 d prior to BRD treatment. The authors reported positive predictive value and sensitivity of the CUSUM prediction method were 91 and 90% (Quimby et al., 2001). However, the disease definition was solely based on treatment records, with previously explained limitations.

New technological developments are arising, which might make behaviour monitoring more affordable and behavioural interpretation easier (Bikker et al., 2014). Nevertheless, it is critical for research and commercial applications to validate new systems and test their accuracy in every species for which the technology is intended, as differences in breed, age and size can be responsible for large variations in accuracy (Goldhawk et al., 2013).

1.3.2 Activity monitoring

Activity monitoring has been already applied for decades in the dairy industry. Pedometers, activity-meters attached around the neck and activity-meters attached to the leg, are frequently used to identify oestrus in cows (Saint-Dizier and Chastant-Maillard, 2012).

Besides physiological changes, activity changes associated with disease and symptoms of disease have also been investigated using activity monitoring in both dairy and beef cattle. For example, lying behaviour recorded by leg-mounted accelerometers was an indicator of lameness in dairy cows (Ito et al., 2010). In beef cattle,
accelerometers provided accurate estimations of lying time to compare differences in lying behaviour of castrated steers before and after castration (White et al., 2008).

Activity monitoring was also applied in BRD-affected cattle. After *M. haemolytica* inoculation, step counts were significantly lower compared to values before inoculation (Hanzlicek et al., 2010). Even in a *M. haemolytica* challenge model resulting in relatively mild clinical signs, challenged calves spent more time lying between the day of infection and 8 d post infection (Theurer et al., 2013b). The promising results from those infection trials encourage further research with accelerometers and pedometers in cattle with naturally occurring BRD.

Although there are several accelerometer and activity monitoring systems there is a lack of systems validated for use in beef cattle. Before systems are used in research and commercial applications accuracy of measurements should be evaluated.

**1.3.3 Cost of automated monitoring systems**

Automated monitoring of behaviour is becoming more accessible and affordable for feedlot operations owing to the ever-evolving industry. Furthermore, it has been proposed that interpretation of multiple behaviour responses might be a better indicator of the true wellness status of an animal (Theurer et al., 2013a). With numerous methods available to monitor behaviour, it is important to determine which specific behaviours need to be monitored and what is the accuracy of the detection method, how much labour is required to implement and interpret the technology, and the expense of the device. Recommendations should be based on thorough economic analyses, coupled with estimates allowing for sensitivity analysis for all variables (Dijkhuizen et al., 1995).
1.4 Project rationale and objectives

The overall aim of this dissertation is to explore methods for earlier and more accurate BRD diagnosis. Feeding behaviour has previously been used to detect BRD in feedlots, but did not relate feeding behaviour to timing of visual detection (Sowell et al., 1999; Buhman et al., 2000), or lacked reliable confirmation of disease status (Quimby et al., 2001). Regardless, prediction in relation to the day of confirmed BRD status is essential to evaluate predictive ability of feeding behaviour for BRD detection. Therefore, chapter 2 was dedicated to exploring the ability of feeding behaviour in terms of time at feedbunk and intake to predict BRD during the days prior to laboratory confirmed BRD.

New methods for feeding and activity behaviour monitoring have been developed and launched. However, critical, independent evaluation of accuracy of behaviour monitoring systems is crucial before technology can be used in commercial and experimental settings. Methods validated for application on beef cattle are scarce. Chapter 3 evaluated 2 new systems for behaviour monitoring, both based on accelerometer technology. The first part of the chapter deals with a system monitoring feeding and rumination behaviour, whereas in the second part, a system monitoring activity and feeding is validated.

Generally, it is expected that objective methods of disease detection will improve detection accuracy because observer bias and fatigue can be avoided (Weary et al., 2009). However, a critical evaluation of economic effects of alternative detection methods is necessary to provide management decision tools for feedlot operators. Chapter 4 focuses
on an economic evaluation of early BRD detection using automated recording systems, which was compared to pen-checking in a decision tree.

Chapter 5 is a rapid systematic review of literature on methods that have been proposed for BRD detection.

In Chapter 6, results of all studies are summarized and implications of findings, as well as proposed future directions, are discussed.
Chapter Two: FEEDING BEHAVIOUR AS AN EARLY PREDICTOR OF
BOVINE RESPIRATORY DISEASE IN NORTH AMERICAN FEEDLOT
SYSTEMS
2.1 Abstract

Bovine respiratory disease (BRD), which can cause substantial losses for feedlot operations, is often difficult to detect based solely on visual observations. The objectives of the current study were to determine a BRD case identification based on clinical and laboratory parameters and assess the value of feeding behaviour for early detection of BRD. Auction-derived, mixed-breed beef steers \( n = 213 \) with an average arrival weight of 294 kg were placed at a southern Alberta commercial feedlot equipped with an automated feed bunk monitoring system. Feeding behaviour was recorded continuously (1-s intervals) for 5 wk after arrival and summarized into meals. Meals were defined as feeding events that were interrupted by less than 300 s non-feeding. Meal intake (g) and meal time (min) were further summarized into daily mean, minimum, maximum and sum, and together with frequency of meals per day, were fit into a discrete survival time analysis with a conditional log-log link. Feedlot staff visually evaluated (pen-checked) health status twice daily. Within 35 d after arrival, 76\% \( n = 165 \) of the steers had one or more clinical signs of BRD (reluctance to move, crusted nose, nasal or ocular discharge, drooped ears or head and gaunt appearance). While 41 blood samples could not be processed due to immediate freezing, for 124 of these steers, complete and differential blood cell count, total serum protein, plasma fibrinogen, serum concentration of haptoglobin (HP) and serum amyloid A (SAA) were determined. The disease definition for BRD was a rectal temperature \( \geq 40.0^\circ \text{C} \), at least two clinical signs of BRD, and HP \( > 0.15 \text{ mg/mL} \). It was noteworthy that 94\% of the 124 steers identified by the feedlot staff with clinical signs of BRD had HP \( > 0.15 \text{ mg/mL} \). An increase in mean meal intake, frequency and mean inter-meal interval was associated with a decreased hazard for
developing BRD 7 d before visual identification ($P < 0.001$). Furthermore, increased mean mealtime, frequency and mean inter-meal interval were associated with a decreased BRD hazard up to 7 d before feedlot staff noticed clinical symptoms ($P < 0.001$). In conclusion, mean intake per meal as well as mean meal time and frequency of meals could be used to predict the hazard of BRD in feedlot cattle 7 d before visual detection and could be considered in commercial feedlot settings once a predictive algorithm has been developed.

2.2 Introduction

Bovine respiratory disease (BRD) remains the most important health concern in the feedlot industry (Smith, 1998; Jim, 2009; Schneider et al., 2009). Diagnosis of BRD in feedlots typically relies on visual appraisal, with low sensitivity and specificity (62 and 63%, respectively; White and Renter, 2009). Two major acute phase proteins (APP) have been used to verify inflammation and tissue damage in cattle with BRD (Nikunen et al., 2007; Ceciliani et al., 2012). Haptoglobin (HP) had a sensitivity of 64 % and specificity of 71 % (Svensson et al., 2007) and serum amyloid A (SAA) had a clinical sensitivity of 100 % and specificity of 46 % (Horadagoda et al., 1999).

To improve disease detection, tools have been developed to objectively measure health and well-being of cattle automatically (Theurer et al., 2013a). Since fever reduces feed intake in mammals (Hart, 1988), feeding behaviour during the first days after arrival has been compared between BRD-affected and healthy cattle. Daily feeding time was shorter in sick cattle in the first days on feed (DOF; Sowell et al., 1999; Buhman et al., 2000).
Feeding behaviour systems record feeding times only (e.g. Ubisense Series 7000 Compact Tag; Ubisense, Denver, CO, USA; Theurer et al., 2013a) or include load cells that measure feed disappearance (intake, e.g. GrowSafe Systems, Airdrie, AB, Canada; Schwartzkopf-Genswein et al., 2011). Reports quantifying changes in feeding behaviour compared to the time of visual detection of disease are limited (Quimby et al., 2001; Silasi, 2007), but could provide the insight needed for commercial development of automated disease-detection systems.

The objectives of the current study were to determine a BRD case identification based on clinical and laboratory parameters and evaluate the associations between timing of visual detection of BRD and daily feeding behaviour (i.e. feeding times as well as meal intake and frequency). We hypothesized that both feeding time and intake variables can be used to detect BRD earlier than visual observation.

2.3 Materials and Methods

All procedures were carried out in accordance with the regulations of the Canadian Council on Animal Care (CCAC, 2009) and were approved by the University of Calgary Veterinary Sciences Animal Care Committee.

2.3.1 Study design, animals and housing

The study included 213 auction-derived, spring-born, mixed-breed steers with an average arrival weight of 294 kg. Steers were delivered on November 2 and 3, 2010 to a typical mid-sized (one-time capacity of 15,000 animal) commercial feedlot ~50 km north of Calgary, AB, Canada. Detailed health and feeding data were collected for 35 d after
arrival. Incoming steers were managed according to the feedlot’s herd health induction protocol and were allocated to a single pen equipped with an automated recording system for individual feeding behaviour (Growsafe Systems Ltd, Airdrie, AB, Canada). At induction, all steers were ear-tagged with a radio frequency transponder (Allflex, Dallas/Ft. Worth, TX, USA), which was also used as a unique identifier for the feeding behaviour recording system. Another ear-tag was used as feedlot identification. Steers were treated with 150 mg ivermectin (Ivomec pour-on; Merial, Baie d’Urfé, QC, Canada) for internal and external parasites. The induction protocol also included vaccinations against clostridial diseases (Vision 7, Merck, Kirkland, QC, Canada), *Histophilus somnus* (Somnu-star Ph, Novartis, Mississauga, ON, Canada), bovine herpes virus-1, bovine viral diarrhea virus types 1 and 2, parainfluenza-3 virus, and bovine respiratory syncytial virus (StarVac 4 plus, Novartis, Mississauga, ON, Canada). Long-acting oxytetracycline 20 mg/kg BW (Bio-mycine 200; Boehringer-Ingelheim, Burlington, ON, Canada) was administered as a metaphylactic treatment against BRD.

The steers were housed in a dirt-floor pen (50 × 60 m; 14 m² of pen space per steer). Feed was delivered daily at 0700 h as a total mixed ration (49.3 % DM) and contained 52.0 % barley silage and 35.3 % tempered barley, 10.0 % wet distillers grain, 2.7 % supplements. Feed and fresh water were available *ad libitum*.

### 2.3.2 Case definition and treatment

True BRD cases were identified at their first incidence during the first 35 DOF (observation period) as follows: every morning and noon one of two experienced feedlot employees separated steers visually suspicious for BRD from their pen mates (“pulling”).
Feedlot employees used the following signs as indicators to support the diagnosis of BRD, and recorded them in a feedlot management program: reluctance to move, crusted nose, nasal or ocular discharge, drooped ears or head, and gaunt appearance. Pulled steers were handled through a chute in the hospital area of the feedlot for physical examination, measuring and recording rectal temperature and treatment. Three blood tubes (7 mL volume/tube; one EDTA and two serum tubes) were collected via jugular venipuncture to measure complete blood cell count, serum HP and APP.

Steers were treated if their rectal temperature was ≥ 40.0°C or if temperature was < 40.0°C but severe signs of sickness (i.e. laboured breathing, severe depression) were present. At the time of first treatment, 9 mg/kg BW enrofloxacin (Baytril®; Bayer, Toronto, ON, Canada) was administered s.c. according to the manufacturer’s recommendations. If clinical signs reappeared (or were still apparent) after 4 d, 40 mg/kg BW florfenicol (Nuflor®; Merck, Kirkland, QC, Canada) was administered s.c. as a second treatment. Steers were returned to their home pen without treatment if temperature was < 40.0°C and no severe sickness was noticed in the treatment chute.

The specific requirements for inclusion in the analysis as true BRD on the pulling day (“case”) were: pulled with ≥ 2 clinical signs of BRD, rectal temperature > 40°C and HP > 0.15 mg/mL (Figure 2.1). At all times when cattle appeared healthy they were used as “control”, with the exception of 7 d prior and 7 d past the pulling event. This period was chosen according to results from previous research that suggested highest predictive values of feeding behaviour up to 7 d before pulling (Silasi, 2007) and indicated continuing altered feeding behaviour after treatment in other infectious diseases (Yeiser et al., 2012).
2.3.3 Laboratory analyses

Whole-blood samples were submitted to a reference laboratory (Antech Diagnostics Ltd, Calgary, AB, Canada) the day they were collected from pulled steers to determine complete blood cell count (CBC), total serum protein (TP) and plasma fibrinogen (FB). Due to extreme weather conditions, including freezing of blood samples immediately after drawing, or the inability to drive from Calgary to the feedlot during those weather conditions, 41 blood samples could not be processed.

Serum blood samples were centrifuged within 24 h after they were collected, aliquoted and stored at -20°C pending determination of SAA and HP. Both APP analyses were carried out using commercially available ELISA kits (Tridelta Development Ltd, Maynooth, Ireland). Serum was thawed and analyzed at room temperature, and diluted (1:500 ratio) for the SAA assay. Results were calculated using the ELISA standard curve, reading the absorption at 450 nm and transferring the values into μg/mL or mg/mL, with a working range of 9.4 to 150 μg/mL for SAA and 0.05 to 3 mg/mL for HP. Mean inter-assay CVs for HP and SAA were 7.2 and 9.4 %, respectively, whereas the intra-assay CVs were < 6.3 and < 7.5 %, respectively.

A laboratory internal reference range was created for HP and SAA from serum samples of healthy mixed-breed weaned steers from two research institutions (n = 16 and 40) and one commercial feedlot (n = 78) also located in Western Canada. None of the reference cattle received any treatments from 6 wk before to 6 wk after the sampling date. As suggested by Horn et al. (1998), extreme outliers [third quartile +1.5 x interquartile
range (IQR)] were excluded from the healthy range. Reference intervals for HP and SAA were defined using the upper 97.5\textsuperscript{th} percentile as the cut-off (Horn et al., 1998).

2.3.4 Feeding data collection

Feeding behaviour records were collected continuously from the day of arrival at the feedlot to 35 d after arrival, when the hazard for first pulling events reached a nadir (Figure 2.2). An electronic monitoring system recorded presence of the steers at the feed bunk by scanning the radio frequency ear-tag at 1-s intervals, enabling measurement of individual bunk attendance frequency, feeding time (s) and intake (g) during the visit (Growsafe Ltd, Airdrie, AB, Canada). The pen was equipped with 32 individual feeding stalls measuring 0.97 × 1.25 × 0.90 m. The system has been described and validated (Schwartzkopf-Genswein et al., 1999; Basarab et al., 2003). All feed intake data presented were measured on an as-fed basis. Feeding time, frequency and intake were summarized into meals. A meal was defined as a feeding event that was not interrupted by > 300 s of non-feeding, based on survival analysis (deHaer and Merks, 1992) and previous studies by Schwartzkopf-Genswein et al. (2002; 2011). Meal time (s) and meal intake (g) were summarized daily into sum, mean, minimum and maximum values for each steer over the entire trial. Frequency was considered as number of meals per day (Table 2.1).

2.3.5 Statistical analysis

Statistical analyses were performed using Stata Version 13.1 (StataCorp LP, College Station, TX, USA). The unit of observation was the steer. The significance level
was set at a $P$-value of 0.05, whereas $P$-values ranging from 0.05 to 0.10 were regarded as trends. Feeding data of all 213 animals were evaluated (individual-animal basis) for biologically unexplainable and missing data. Nine steers were excluded due to inconsistent feeding records with $> 4$ consecutive days of missing data.

The pulled population was described on the day of pulling using traditionally used laboratory parameters (CBC, differential blood count, TP, and FB). Results were categorized as within or outside the reference range.

A model was created for each of the 7 d before first pulling to assess when and if BRD can be detected earlier in comparison to pulling using daily summarized meal time, between meal time, meal intake and meal frequency. To account for the changing number of steers at risk of BRD over time, discrete time hazard models were used to predict BRD. Proportional hazards were calculated with a complementary log-log link, reflecting the underlying continuous metric for time. The changing hazard throughout the 35 DOF was accounted for by including a 4th order polynomial of DOF (Singer and Willett, 2003). For steers that were never treated throughout the 35 d observation period all days were labeled “control”. Additionally, the days up to 7 d before pulling and from 8 d past pulling were labeled “control” in the steers with BRD if no further treatments were applied to the steer. The day before BRD according to our definition was labeled “case” in the dataset. All other days between -8 and +8 relative to pulling were excluded (Figure 2.3). Data from steers that were pulled but did not meet the BRD case definition were also excluded from the analyses. Relapses and retreats were not included in the analysis, as blood was only drawn from first-pull cattle.
For each of the 7 d before pulling, two separate model datasets were analyzed to account for different monitoring abilities in feeding behaviour-recording systems. The first model set included only time measures (i.e. mean, minimum, maximum, sum of meal time and inter-meal interval) and frequency of meals per day, whereas the second model set included all time measures and summarized meal intake variables (g) (i.e. mean, minimum, maximum, sum of intake). Individual animal probabilities to be visually detected were predicted using the models. The cut-off for feeding behaviour-based identification was a probability exceeding the daily incidence of visually based BRD identification. With no gold standard available to define true BRD, sensitivity and specificity could not be defined. However, the percentages of visually detected steers that were detected based on feeding behaviour and visually undetected steers that were also not detected based on feeding behaviour were calculated as an estimate of detection accuracy.

Before model fitting, a correlation matrix was fit to all feeding behaviour predictors to avoid multicollinearity. Variables with an \( r > 0.70 \) were assessed in a univariate analysis with the outcome variable BRD; the variable with the lowest impact was not included in the model. Correlations were high between mean feeding time per meal and the longest meal event (\( r = 0.71 \)), mean feed intake per meal and the largest meal (\( r = 0.73 \)), and smallest and shortest meal (\( r = 0.83 \)). Additionally, since sum is the product of mean and frequency, both means and sums were analyzed in univariate analysis and the variable with the stronger effect on BRD was chosen. All other variables were included in the first model and stepwise eliminated if \( P > 0.05 \). Confounding was considered present if one or more coefficients changed by \( > 20\% \) when removing a
variable. There was no evidence for confounding by any of the excluded variables. The best fit was assessed with Akaike Information Criterion (AIC). To account for hazard change over the observation period, DOF were modelled as a fourth-order polynomial (Dohoo et al., 2009). The results can be interpreted as follows: hazard ratio below 1 indicates decreased hazard throughout the observation time with a 1-unit increase in the variable, conversely a hazard ratio above 1 indicates increased hazard with a 1-unit increase in the variable.

2.4 Results

2.4.1 Laboratory results

Median SAA was 18.67 μg/mL (IQR: 4.85 to 38.02 μg/ml) with a 97.5th percentile at 80.31 μg/mL. Median HP in the laboratory internal reference group was 0.08 (IQR: 0.06-0.10 mg/mL) with the 97.5th percentile at 0.15 mg/mL. Ninety-four percent of the pulled population had HP values > 0.08 mg/mL. A total of 51.8 and 83.9% of cases diverged from the laboratory-provided reference range in the neutrophil counts or the red blood cell count, respectively (Table 2.2).

2.4.2 Case identification

Of the entire study population, 165 (77%) steers were pulled at least once, including 9 steers with incomplete feeding records and 41 steers with missing blood samples. Feedlot staff re-treated 42 (40%) and 11 (37%) of the first-treated steers with a rectal temperature
≥ 40.0°C and < 40.0°C, respectively. Seventeen steers (58%) that were pulled but not treated at first pulling were subsequently pulled again and required treatment.

Sixty-six steers met the case definition for BRD, whereas 47 steers were not pulled during the first 35 d (controls). The BRD hazard on each given day was 2.15%.

**BRD prediction with intake variables**

Throughout the 7 d before pulling, BRD hazard decreased with increasing mean intake per meal \( (P < 0.001) \), frequency \( (P < 0.001) \) and inter-meal interval \( (P < 0.001) \) in the model including feed intake measures. Throughout the entire 35-d period, BRD hazard decreased between 29% (SEM 4%) and 24% (SEM 3%) for steers with a 100 g increase in intake per meal varying per day before pulling. Furthermore, the smallest meal (minimum intake) was a significant predictor 2 days before pulling \( (P = 0.02) \), increasing the BRD hazard by 31% (SEM 15%) with an increase of 100 g in the minimum meal size. When feed intake variables were available, an increase in frequency by one meal per day resulted in a reduction of the BRD hazard between 11% (SEM 2%) and 18% (SEM 4%) in the week before pulling.

Five days before visual detection, 82% of the cases were detected based on intake variables using the probability of daily visual detection (2.15%) as cut-off and 78% of visually healthy steers were classified healthy. Between 1 and 3 d prior visual detection 80 to 81% of the cases were predicted as BRD cases by the survival model and 76 to 79% of controls were classified healthy. On d 7 before visual detection 61% of the cases were detected whereas 84% of the controls were classified healthy (Figure 2.4).
BRD prediction with time variables

Mean feeding time ($P < 0.001$), frequency ($P < 0.001$) and inter-meal interval ($P < 0.001$) were significant predictors throughout the week before pulling in the model set without intake measures. Additionally, at 4 d before visual detection of BRD, the shortest meal was a significant predictor for BRD, if only time variables were considered. The hazard for BRD decreased by 54% (SEM 17%) with an increase of 1 min in the shortest meal ($P = 0.04$) if the remaining variables stayed constant. Moreover, the hazard for BRD decreased between 13% (SEM 3%) and 17% (SEM 3%) for every 1-min increase in feeding time per meal. Frequency increase by one meal per day resulted in a hazard decrease between 16% (SEM 2%) and 21% (SEM 2%). A 1-h increase in the mean time between two events significantly decreased BRD hazard (between 56% on day -5 and 21% on day -1) (Table 2.3).

The BRD hazard model based on time variables predicted BRD in 81% of the cases 3 d before visual identification while 77% of the visually healthy steers were classified healthy using feeding behaviour. On the contrary, 4, 6 and 7 d before visual detection less than 72% of the cases were identified by time variables and more than 77 (d 4) up to 84% (d 7) of the controls were classified healthy using feeding time variables (Figure 2.4).

2.5 Discussion

The present study identified a decrease in the BRD hazard with an increase in mean feed intake per meal, mean meal time as well as frequency of meals per day as early as 1 wk before visual identification, with highest prediction between 5 and 1 d
before visual detection. Mean feed intake per meal appeared to be a useful tool for identifying susceptible cattle in the early stages of BRD. The BRD hazard decreased by at least 22%, with a 100 g increase of intake per meal throughout the week before pulling. In addition, steers with longer mean meals had lower hazards for visual BRD during the following week. Other feedlot studies compared total feeding time per day and frequency per day between sick and healthy animals in relation to DOF. Interestingly, they reported that frequency and total feeding time were lower between d 11 and 27, but greater between d 28 and 57 in sick cattle after arrival, which were attributed to post-sickness compensation (Buhman et al., 2000). Additionally, the Cumulative Sum Chart (CUMSUM) method using cumulative presence and absence at the feedbunk identified 90% of the apparently sick feedlot cattle 4.5 d earlier in the disease process (Quimby et al., 2001). In other studies, accuracy of predictive models was highest from 1 to 7 d before pulling (Silasi, 2007). Similar to feedlot cattle, in dairy cattle, daily feed intake, feeding time and frequency predicted metritis and other, non-infectious diseases. Furthermore, cows with lower intakes, frequency and shorter daily feeding time were readily identified as being high-risk for disease (Huzzey et al., 2007; Gonzalez et al., 2008b; Jawor et al., 2012). The advantage of the current study compared to previous studies was the ability to compare specific feeding behaviour traits between sick and healthy steers in relation to the day of visual identification (in a group of cattle that was assembled over 24 h). Furthermore, in the present study a specific case definition was used rather than relying only on visual appraisal. The current study additionally explored intake variables, which to our knowledge have not yet been described in relation to BRD identification. A review, however, argued that anorexia observed in ill animals is part of a
coordinated strategy to fight disease. To preserve energy animals would according to this
theory rest more and decrease feeding and reproductive activities (Weary et al., 2009).
This theory is further supported by experimentally induced endotoxemia, which provided
evidence that with mounting immune response appetite in humans decreased (Pollmacher et al., 2002).

Control steers fed on average 9.7 min per meal, with a frequency of
approximately 12 meals per day, whereas BRD case steers fed on average between 7.6
and 8.9 min with a frequency of 9.7 (d -7) to 12.5 (d -5) per day. Feed intake for the non-
pulled cattle population was on average 1 kg per meal while pulled steers fed 0.4 and 0.5
kg per meal during the 7 d before pulling. Similar times and intakes have been reported
for healthy cattle (Basarab et al., 2003; Schwartzkopf-Genswein et al., 2011). However, a
restricted number of feeding places (32/213 steers) as opposed to open feedbunks with
unrestricted access could have reduced dry matter intake (Gonzalez et al., 2008a).
Although limited bunk space for feedlot cattle is common (Alberta Agriculture and Rural
Development, 2000) this effect needs to be further investigated, specifically in feedlot
cattle experiencing health problems.

Fifty-seven percent of the visually identified and treated steers were classified as
ture BRD cases. This percentage was achieved by serial evaluation of the health status of
pulled steers. The first step after visual identification and verification of fever (≥ 40º C)
was serum testing using HP, a highly specific marker of inflammation, which has been
previously described in a field study to successfully identify calves with BRD and to
differentiate healthy from recovered cattle (Humblet et al., 2004). An additional factor for
the case definition was the number of clinical signs of BRD. The clinical signs included
in the disease definition are regularly used by pen-checkers to identify cattle in need of further evaluation. In this study, steers with high rectal temperature more frequently displayed multiple signs of sickness compared to those with normal rectal temperature. Visual appraisal has low specificity and high variability among observers (Amrine et al., 2013). However, specificity of diagnostics can be increased if additional measures of disease status are included through serial testing (Dohoo et al., 2009). Although a widely accepted reference standard for BRD has not been described (Schaefer et al., 2012), it is essential to have a sound case definition when new technology is being tested or validated.

The high number of steers with elevated HP values (94%) as opposed to the relatively low numbers of steers above the cut-off for other blood end points resulted in inclusion of HP in the disease definition. The value of HP as a useful clinical parameter to measure the inflammatory response in cattle with BRD has been supported in numerous publications (Godson et al., 1996; Heegaard et al., 2000; Humblet et al., 2004; Orro et al., 2011). The cut-off for HP (0.15 mg/mL) used to define sick steers in the present study has been reported (Buhman et al., 2000) and lies within the range of other publications (Godson et al., 1996; Heegaard et al., 2000; Humblet et al., 2004). Furthermore, the current study concurred with the findings in previous publications that white blood cell count might not be a good parameter to confirm inflammation due to pneumonia (Nikunen et al., 2007; Richeson et al., 2013). In agreement with previous publications, red blood cell count was greater than the reference value in the majority of pulled steers (Fraser et al., 2014), with a low effect on the hematocrit. The high red blood cell count but normal hematocrit in BRD affected cattle should be further investigated.
The treatment rate in the present study was high at 65% and most steers were treated early after arrival. This exceptionally high treatment rate was attributed to a sudden temperature drop and snowstorm in the first 10 DOF. Weather during the first 45 DOF was reported to be a significant risk factor for BRD in commercial feedlots (Cernicchiaro et al., 2012a). Additionally, the induction protocol was treatment with long acting oxytetracycline, instead of the commonly used tulathromycin as a metaphylactic treatment. Based on a recent meta-analysis, oxytetracycline has low efficacy for treatment of BRD compared to tulathromycin, which will also explain the high treatment rate (O'Connor et al., 2013).

The present study could contribute to the development of algorithms to prospectively identify BRD in feedlots. Early treatment decreases negative effects of sickness and increases treatment efficacy (Ferran et al., 2011). Feeding behaviour observations can and should be assessed for other economically important diseases besides BRD in feedlots. In that regard, the current study provided the basis for comparisons between clinically ill and visually healthy feedlot cattle. Future research should evaluate the economic value of early disease identification in feedlots.

A weakness of the current study was the missing clinical evaluation and blood sampling of steers not affected by clinical sickness. The researchers decided not to disturb the feedlot routine since pulling and examining healthy animals would be expected to have altered their feeding behaviour, growth performance, and potentially health status. It is likely that this missing information led to an underestimation of the true difference in feeding behaviour between healthy and sick cattle. Additionally, the environmental conditions were specific for the northern area of cattle feeding in the US.
and Canada (AB). The study should be repeated under different environmental conditions to ensure generalizability of the results.

In conclusion, mean intake per meal as well as mean meal time and frequency of meals had merit to predict the hazard of BRD in feedlot cattle 7 d before visual detection and could be used to develop predictive algorithms for commercial application in feedlot settings.
Table 2.1: Descriptive statistics of feeding behaviour variables for steers between d 7 and d 1 before pulling and steers that were visually healthy during the entire 35 d period

<table>
<thead>
<tr>
<th></th>
<th>d -7</th>
<th>d -6</th>
<th>d -5</th>
<th>d -4</th>
<th>d -3</th>
<th>d -2</th>
<th>d -1</th>
<th>Healthy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meal¹ intake, 100 g</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>4.2 (2.8)</td>
<td>4.7 (3.1)</td>
<td>5.2 (3.1)</td>
<td>5.4 (3.2)</td>
<td>5.3 (3.1)</td>
<td>5.3 (3.2)</td>
<td>5.1 (3.0)</td>
<td>10.0 (5.2)</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.3 (0.7)</td>
<td>0.3 (1.1)</td>
<td>0.1 (0.4)</td>
<td>0.1 (0.2)</td>
<td>0.2 (0.6)</td>
<td>0.3 (1.0)</td>
<td>0.2 (0.9)</td>
<td>0.8 (2.4)</td>
</tr>
<tr>
<td>Maximum</td>
<td>12.7 (7.2)</td>
<td>15.7 (9.9)</td>
<td>17.8 (9.4)</td>
<td>18.9</td>
<td>17.2 (8.9)</td>
<td>16.9 (9.0)</td>
<td>16.2 (9.9)</td>
<td>29.2 (13.0)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Meal¹ time, min</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>8.6 (5.5)</td>
<td>8.8 (5.4)</td>
<td>8.9 (4.5)</td>
<td>8.8 (5.0)</td>
<td>8.4 (5.1)</td>
<td>8.2 (4.9)</td>
<td>7.6 (4.9)</td>
<td>9.7 (5.0)</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.4 (0.6)</td>
<td>0.8 (3.0)</td>
<td>0.3 (0.6)</td>
<td>0.2 (0.3)</td>
<td>0.4 (0.9)</td>
<td>0.6 (1.3)</td>
<td>0.5 (1.1)</td>
<td>0.8 (2.1)</td>
</tr>
<tr>
<td>Maximum</td>
<td>27.4</td>
<td>28.5</td>
<td>30.8</td>
<td>31.5</td>
<td>27.5</td>
<td>25.6</td>
<td>25.9</td>
<td>30.4</td>
</tr>
<tr>
<td></td>
<td>(18.8)</td>
<td>(17.0)</td>
<td>(18.6)</td>
<td>(18.6)</td>
<td>(18.2)</td>
<td>(14.7)</td>
<td>(17.8)</td>
<td>(14.4)</td>
</tr>
<tr>
<td><strong>Inter-meal interval¹, h</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>2.9 (3.8)</td>
<td>3.3 (5.3)</td>
<td>2.4 (3.5)</td>
<td>2.1 (1.8)</td>
<td>3.0 (4.6)</td>
<td>2.2 (1.3)</td>
<td>3.5 (4.5)</td>
<td>2.0 (1.7)</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.3 (0.7)</td>
<td>0.9 (4.1)</td>
<td>0.1 (0.2)</td>
<td>0.1 (0.1)</td>
<td>0.2 (0.1)</td>
<td>0.1 (0.1)</td>
<td>0.4 (1.1)</td>
<td>0.2 (0.9)</td>
</tr>
<tr>
<td>Maximum</td>
<td>8.7 (4.2)</td>
<td>9.0 (6.6)</td>
<td>9.0 (5.7)</td>
<td>9.4 (5.6)</td>
<td>9.1 (5.3)</td>
<td>9.8 (5.9)</td>
<td>11.2 (5.4)</td>
<td>9.3 (4.1)</td>
</tr>
</tbody>
</table>

32
<table>
<thead>
<tr>
<th></th>
<th>d -7</th>
<th>d -6</th>
<th>d -5</th>
<th>d -4</th>
<th>d -3</th>
<th>d -2</th>
<th>d -1</th>
<th>Healthy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of meals(^1)</td>
<td>9.7 (4.9)</td>
<td>10.6 (5.5)</td>
<td>12.5 (5.1)</td>
<td>12.1 (5.8)</td>
<td>11.5 (5.8)</td>
<td>11.5 (4.9)</td>
<td>10.4 (5.0)</td>
<td>12.3 (4.8)</td>
</tr>
</tbody>
</table>

\(^1\)feeding event with an interruption < 300 s
Table 2.2: Complete and differential blood cell count and acute phase proteins at first pull and percentage of steers greater or lower than the reference interval (RI) for haptoglobin-positive cattle with a rectal temperature $\geq 40.0^\circ C$ and $\geq 2$ clinical signs of bovine respiratory disease (BRD) ($n = 66$)

<table>
<thead>
<tr>
<th></th>
<th>Median</th>
<th>IQR(^1)</th>
<th>RI(^2)</th>
<th>% outside RI(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White blood cell count, 10(^9)/L</td>
<td>10.0</td>
<td>8.6-12.3</td>
<td>4-11</td>
<td>51.8</td>
</tr>
<tr>
<td>Neutrophils, 10(^9)/L</td>
<td>4.1</td>
<td>2.6-5.7</td>
<td>0.6-4.0</td>
<td>51.8</td>
</tr>
<tr>
<td>Lymphocytes, 10(^9)/L</td>
<td>5.7</td>
<td>5.1-6.9</td>
<td>2.5-7.5</td>
<td>19.6</td>
</tr>
<tr>
<td>Monocytes, 10(^9)/L</td>
<td>0.2</td>
<td>0.1-0.3</td>
<td>0.0-0.8</td>
<td>0</td>
</tr>
<tr>
<td>Eosinophils, 10(^9)/L</td>
<td>0.1</td>
<td>0.0-0.2</td>
<td>0-2.4</td>
<td>0</td>
</tr>
<tr>
<td>Basophils, 10(^9)/L</td>
<td>0.1</td>
<td>0.0-0.1</td>
<td>0-0.2</td>
<td>0</td>
</tr>
<tr>
<td>Red blood cell count, 10(^12)/L</td>
<td>10.1</td>
<td>9.4-10.8</td>
<td>6-9</td>
<td>83.9</td>
</tr>
<tr>
<td>Haemoglobin, g/L</td>
<td>130</td>
<td>122.5-134.5</td>
<td>100-150</td>
<td>3.6</td>
</tr>
<tr>
<td>Hematocrit, %</td>
<td>37</td>
<td>34-38</td>
<td>30-46</td>
<td>1.8</td>
</tr>
<tr>
<td>Total protein, g/L</td>
<td>69</td>
<td>67-75</td>
<td>67-75</td>
<td>8.8</td>
</tr>
<tr>
<td>Fibrinogen, g/L</td>
<td>5.7</td>
<td>4.5-7.3</td>
<td>3-7</td>
<td>30.4</td>
</tr>
<tr>
<td>Haptoglobin, mg/mL</td>
<td>2.6</td>
<td>1.4-2.4</td>
<td>0-0.15</td>
<td>n/a</td>
</tr>
<tr>
<td>Serum Amyloid A, g/mL</td>
<td>127.2</td>
<td>85.8-143.7</td>
<td>0-80.3</td>
<td>75.4</td>
</tr>
</tbody>
</table>

\(^1\)IQR = Interquartile range

\(^2\)RI = Reference interval

n/a = not applicable
Table 2.3: Hazard Ratios for variables included in the final models to predict visual identification of bovine respiratory disease (BRD) in the first 35 d after arrival to the feedlot, with (Y) and without (N) feed intake measures; modeled between 1 and 7 d before visual identification (d -1 to d -7). The analyses included polynomial models of days on feed

<table>
<thead>
<tr>
<th>Variable</th>
<th>d -7</th>
<th>d -6</th>
<th>d -5</th>
<th>d -4</th>
<th>d -3</th>
<th>d -2</th>
<th>d -1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter-meal interval, h</td>
<td>0.68</td>
<td>0.79</td>
<td>0.75</td>
<td>0.85</td>
<td>0.44</td>
<td>0.58</td>
<td>0.58</td>
</tr>
<tr>
<td>Meal time, min</td>
<td>0.87</td>
<td>NS</td>
<td>0.86</td>
<td>NS</td>
<td>0.87</td>
<td>NS</td>
<td>0.89</td>
</tr>
<tr>
<td>Shortest meal, min</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>0.46</td>
<td>NS</td>
<td>0.86</td>
</tr>
<tr>
<td>Frequency</td>
<td>0.79</td>
<td>0.86</td>
<td>0.80</td>
<td>0.86</td>
<td>0.84</td>
<td>0.89</td>
<td>0.81</td>
</tr>
<tr>
<td>Intake, 100g/meal</td>
<td>n/a</td>
<td>0.71</td>
<td>n/a</td>
<td>0.72</td>
<td>n/a</td>
<td>0.74</td>
<td>n/a</td>
</tr>
<tr>
<td>Smallest meal, g</td>
<td>n/a</td>
<td>NS</td>
<td>n/a</td>
<td>NS</td>
<td>n/a</td>
<td>NS</td>
<td>n/a</td>
</tr>
<tr>
<td>Days on feed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>linear</td>
<td>0.38</td>
<td>0.58</td>
<td>0.39</td>
<td>0.61</td>
<td>0.27</td>
<td>0.40</td>
<td>0.24</td>
</tr>
<tr>
<td>quadratic</td>
<td>1.08</td>
<td>0.83</td>
<td>1.12</td>
<td>0.87</td>
<td>0.97</td>
<td>0.74</td>
<td>0.79</td>
</tr>
<tr>
<td>cubic</td>
<td>0.93</td>
<td>0.90</td>
<td>0.88</td>
<td>0.85</td>
<td>0.75</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td>4th order</td>
<td>0.62</td>
<td>0.75</td>
<td>0.61</td>
<td>0.60</td>
<td>0.37</td>
<td>0.42</td>
<td>0.39</td>
</tr>
<tr>
<td>AIC^1</td>
<td>352</td>
<td>321</td>
<td>410</td>
<td>377</td>
<td>413</td>
<td>392</td>
<td>430</td>
</tr>
</tbody>
</table>

AIC^1
<table>
<thead>
<tr>
<th></th>
<th>d-7</th>
<th>d-6</th>
<th>d-5</th>
<th>d-4</th>
<th>d-3</th>
<th>d-2</th>
<th>d-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>BIC$^2$</td>
<td>393</td>
<td>363</td>
<td>451</td>
<td>419</td>
<td>455</td>
<td>434</td>
<td>477</td>
</tr>
</tbody>
</table>

NS = not significant ($P > 0.05$), not included in the final model

n/a = not applicable

$^1$AIC = Akaike Information Criterion

$^2$BIC = Bayesian Information Criterion
Figure 2.1: Selection criteria and sample sizes for cases and controls.

* Missing feeding (n = 9), missing blood (n = 41)
Figure 2.2: First visual detection a) over the entire feeding period, and b) within 35 d after arrival.
Figure 2.3: Demonstration of data collection over observation time with an example of a pulling event on day 12.
Figure 2.4: Percent of case (solid lines) and control (dashed lines) steers detected by BRD hazard model using time variables only (black lines, squares) and including intake variables (gray lines, triangle).
Chapter Three: EXPLORING ALTERNATIVE METHODS OF BRD DETECTION
3.1 Accuracy of an ear tag-attached accelerometer to monitor rumination and feeding behaviour in feedlot cattle

3.1.1 Abstract

Early identification of sick cattle increases treatment success and decreases mortality. Continuous automated records of behaviour can be used to identify sick cattle early in the disease process. The objective was to evaluate accuracy of an ear tag-attached accelerometer (SensOor) that quantified ear movements and estimated feeding and rumination time through a proprietary algorithm. Accelerometers were attached to the ear tag of 18 steers with an initial mean bodyweight (BW) of 326 ± 46 kg. The manufacturer’s proprietary software was used to determine time spent “feeding”, “ruminating”, “active”, and “resting”. Direct visual observation was used to validate the accelerometer. Sensitivity, specificity and predictive values were calculated for rumination and feeding separately. Repeated measures were accounted for using mixed model logistic regression. Single minutes of either feeding or rumination in a run of other behaviour minutes were changed to the preceding behaviour. Accuracy and precision of hourly recorded feeding and rumination times were assessed using the concordance correlation coefficient adjusted for repeated measurements. Sensitivity and specificity were 95 and 76% for feeding and were 49 and 96% for rumination, respectively. Concordance correlation between observations and the sensor were 0.79 (95% CI: 0.61-0.85) and 0.44 (95% CI 0.23-0.60) for feeding and rumination, respectively. There was large variability among steers, with concordance correlations ranging from 0.09 to 0.98
for rumination time and from 0.58 to 0.96 for feeding time. We conclude that the accelerometer is a promising monitoring system for feeding behaviour.

3.1.2 Introduction

Feeding and rumination behaviour can be monitored to assess health status of ruminants. For example, records of feeding behaviour have been used to detect bovine respiratory disease in feedlot cattle (Sowell et al., 1999; Borderas et al., 2008) and monitoring rumination behaviour helped detect subacute ruminal acidosis in dairy cows (DeVries et al., 2009). However, behavioural assessments using visual appraisal are very time consuming and typically done only once or twice daily for relatively short intervals. Consequently, monitoring devices have been developed to continuously measure either feeding (Mendes et al., 2011) or rumination behaviour (Elischer et al., 2013). Such devices are based on radio-frequency identification at the feedbunk (Schwartzkopf-Genswein et al., 2011), movements of the jaw (Beauchemin et al., 1989), or acoustics (Schirmann et al., 2009).

Based on observed differences in movement patterns of cows’ ears, a system has been developed to monitor ear movements and calculate feeding, rumination, activity, and resting times (SensOor, Agis Automatisering BV, Harmelen, the Netherlands). A three-dimensional accelerometer is attached to the radio frequency identification ear tag and an online application provided by the manufacturer records time spent feeding, ruminating, activity, and resting time per hour and per day. A validation study in dairy cows suggests that this accelerometer was accurate for calculating feeding and rumination times (Bikker et al., 2014). However, some monitoring systems, which have high
accuracy in dairy cattle, do not perform as well in beef cattle (Goldhawk et al., 2013). The objectives of this study were to evaluate: 1) sensitivity and specificity of the accelerometer to detect rumination and feeding behaviour in beef cattle; and 2) accuracy of time spent ruminating and feeding calculated by the accelerometer.

3.1.3 Material and Methods

The University of Calgary Animal Care Committee reviewed and approved all procedures used (AC13-0104). The study was conducted in August 2013 at the Agriculture and Agri-Food Canada, Lacombe Research Centre (Lacombe, AB, Canada). Eighteen Hereford x Angus yearling steers with an initial mean BW of 326 kg (SD ± 46 kg) were group-housed in an outdoor dirt floor pen. Approximately 1/3 of the pen was sheltered and closed on 3 sides. Steers were slick-bunk fed with 100% barley silage, once daily at 0830 h.

Two observers were trained to identify feeding and rumination. The observers discussed and agreed on the definition of rumination and feeding prior to the start of the experiment. First, observers watched video recordings of rumination and feeding. Second, both observers monitored and discussed the behaviour of the same two steers in the pen for 2 h. The onset of a rumination bout was defined as the time when regurgitation occurred, namely when a bolus came up the oesophagus and reached the mouth (Schirmann et al., 2009). The end of a rumination bout was the minute the last bolus was swallowed (> 1 min between two boluses was considered a new rumination bout). Observers recorded the start time for feeding as soon as the steer had its head over the feed bunk and started licking and chewing movements. The end of the feeding bout
was defined when the steer stepped back from the feed bunk and stopped licking and chewing (Bikker et al., 2014). If the head of the observed steer was not fully visible, the minutes of non-observation were marked and excluded from analysis (n = 82 min).

Observers recorded behaviour two or three days per week during the study period (total, 13 d). Observation periods lasted between 72 and 240 min (mean 126 min). The earliest observation started at 0430 h and the latest finished at 2200 h. Every observation period, two steers were selected randomly for observation, with no steer being observed > 9 times. On average, each steer was observed for 5 (SD ± 2) observation periods (Table 3.1).

Inter-observer variability was measured by having both observers independently record the behaviour of the same two steers for 2 h, three times during the study period (total of 6 h). The observers did not communicate and could not view each other’s records. Pearson’s correlation coefficient for paired observations of feeding bouts (n = 58) and rumination bouts (n = 16) between the two observers to assess inter-observer reliability was r > 0.98 for all comparisons.

Feeding and rumination times were monitored continuously using the accelerometer, which was mounted to the RFID tag (Allflex, Dallas/Ft. Worth, TX, USA), placed in the proximal half of the ear between the two cartilage folds. Raw data were transmitted every minute through radio frequency technology (ZigBee Alliance, San Ramon, CA, USA), via router and coordinator to a computer in the office. The working frequencies of RFID tags and accelerometers (134.2 kHz and 2.4 GHz, respectively) did not interfere. An online application (Cowmanager, Agis Automatisering BV, Harmelen, The Netherlands) classified each minute with a proprietary algorithm as 1 of 4 behaviour
categories: “feeding”, “ruminating”, “active”, and “resting”.

Live observations were used as reference standard for comparison with the accelerometer. Statistical analyses and data editing were performed using Stata Version 13.1 (StataCorp LP, College Station, TX, USA). Single feeding or rumination minutes in a run of other behaviour were converted to the preceding behaviour by applying a filter in the accelerometer data (Ledgerwood et al., 2010).

Accuracy of the accelerometer was tested qualitatively and quantitatively. First, sensitivity, specificity, positive and negative predictive values were calculated to assess accuracy of feeding and ruminating per minute. Steer identification was included as a random effect in a mixed logistic regression, to account for clustering within individuals (Genders et al., 2012). Second, records were summarized hourly to assess accuracy of quantitative outcomes (duration of feeding and rumination). The R package (R Foundation for Statistical Computing, Vienna, Austria) CCCRM was used to calculate concordance correlation coefficient on hourly-summarized records adjusted for random steer effect to compare results of visual versus accelerometer-recorded data (Carrasco et al., 2013). In comparison to simple Pearson’s correlation, concordance correlation reflects the level of agreement including a location-shift parameter and a scale-shift parameter that measures the difference between the slope and perfect correlation (45° angle). Bland-Altman graphs were used for graphical representations of the residuals for paired measurements (Dohoo et al., 2009).
3.1.4 Results

Observers recorded 10,252 min of behaviour on 18 steers distributed over 13 d (Table 3.2). Of the total observation time, steers were observed as feeding for 2,692 min (26%) and ruminating for 2,359 min (23%). Mean observed feeding time across all steers was 10.8 ± 15.0 min/h and average rumination time was 9.5 ± 13.9 min/h. When a 1-min filter was applied, sensitivity increased from 93 to 95% (95% CI: 93-96%) and 48 to 49% (95% CI: 34-64%) for feeding and rumination, respectively (Table 3.3). Furthermore, specificity increased from 70 to 76% (95% CI: 69-81%) and 94 to 96% (95% CI: 94-98%).

Concordance correlations between observed and accelerometer-recorded feeding and rumination time were CCC = 0.79 and 0.44. On average, observed feeding was 6.6 min (± 8.7 min) shorter and rumination 2.7 min (± 9.7 min) longer per observed hour than estimated by the accelerometer (Figure 3.1). Specifically, when no filter was applied, the accelerometer misclassified 32% of observed rumination minutes as feeding minutes, 15% as “active” and 2% as “resting”. Conversely, 2% of observed feeding minutes were classified as rumination by the sensor (Table 3.2). Variability among steers ranged from concordance correlations 0.09 to 0.98 for rumination time and from 0.58 to 0.96 for feeding time.

3.1.5 Discussion

The ear tag-attached accelerometer provided good sensitivity, but only moderate specificity to estimate feeding. On the contrary, rumination monitoring by the
accelerometer had high specificity, but low to moderate sensitivity. Therefore, the accelerometer seemed to be a promising tool to measure feeding behaviour in beef cattle, but needs improvement for measuring rumination.

The good concordance correlation between observed and calculated feeding time by the accelerometer was in agreement with a concordance correlation of 0.75 between observed and calculated feeding time in dairy cattle assessed with the same technology (Bikker et al., 2014). Other technologies, including the Growsafe system (Growsafe Ltd., Airdrie, AB, Canada) and the Insentec monitoring system (Insentec, Marknesse, The Netherlands), have been validated for recording feeding behaviour in beef cattle. Although these systems are highly accurate and have the ability to measure intake (Chapinal et al., 2007; Schwartzkopf-Genswein et al., 2011), they are based on individual feed bunks, allowing only single-animal access to a limited number of bunks. Conversely, the accelerometer enabled monitoring of natural cattle behaviour, feeding simultaneously (Rook and Huckle, 1995), and does not require any adaptation period. Notwithstanding, an important limitation is that feed intake cannot be measured with the accelerometer.

Concordance correlation for rumination monitoring compared to observations was low to moderate. Conversely, in dairy cattle, the same system had a high concordance correlation (CCC = 0.93) between observed rumination times and estimates by the accelerometer (Bikker et al., 2014). However, the cattle used in the current study were fed a different diet (barley silage vs. partially mixed ration or total mixed ration), differed in breed (Hereford-Angus vs. Holstein Friesian), sex (male castrated vs. female) and age (yearling vs. lactating dairy cow) compared to the previous study, which could have accounted for the differences. Similar to this study, an acoustic sensor to monitor
rumination was tested in dairy cattle and had a high correlation to visual observation ($r$ ranged from 0.86 to 0.96; Schirmann et al., 2009). When tested on beef cattle (Goldhawk et al., 2013) and younger Holstein cattle (< 9 mo) (Burfeind et al., 2011), the correlation was only 0.24 ($\pm$ 0.07) and between 0.47 and 0.89, which changed with age, respectively. This previously reported lack of correlation, therefore, highlights the differences between the two types of cattle.

The inter-animal variation in correlation between estimates provided by observations and the accelerometer can only speculatively be attributed to ear movement differences between cattle. Whereas most of the steers had concordance correlations between 0.41 and 0.98, concordance correlation in one individual was as low as 0.09 for rumination. When age, weight and individual standardized head pictures of the steers taken in the chute at processing were compared, no explanation for the variation could be suggested. Interestingly, Burfeind et al. (2011) reported similar variation of accuracy among young calves when they used acoustic methods to monitor rumination. However, although the accelerometer did not provide perfect estimates in all steers, it predicted rumination better than a previously validated system in most beef cattle (Goldhawk et al., 2013). Furthermore, it is noteworthy that there are currently few commercial options to monitor rumination.

The moderate specificity of feeding monitoring in the present study might be explained by head movements associated with fly defense, as cattle use their heads, ears, tails, legs, and skin movements to defend themselves from flies (Dougherty et al., 1993). Ruminating steers frequently laid down in the shaded area with limited ventilation compared to the feed bunk, which was situated in the open part of the pen. This resulted
in a higher fly burden during rumination compared to feeding. Additionally, a high proportion of rumination minutes were classified as feeding by the accelerometer. Based on the high inter-observer correlation, however, we concluded that errors due to observers’ misinterpretations were minimal.

This study focused on evaluating the sensitivity, specificity and accuracy of the accelerometer to measure feeding and rumination behaviour, as most applicable to the beef industry. However, since the system additionally records activity and resting, these should be evaluated in future studies.

In conclusion the ear tag-attached accelerometer was a promising tool to measure feeding behaviour in beef cattle. Its associated algorithm, however, might need to be optimized to better differentiate rumination from feeding in beef cattle.
Table 3.1: Observational times in min (% of total) per steer

<table>
<thead>
<tr>
<th>Steer #</th>
<th>Feeding</th>
<th>Ruminating</th>
<th>Total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>243 (25)</td>
<td>270 (28)</td>
<td>965</td>
</tr>
<tr>
<td>2</td>
<td>109 (31)</td>
<td>48 (14)</td>
<td>355</td>
</tr>
<tr>
<td>3</td>
<td>91 (22)</td>
<td>83 (20)</td>
<td>409</td>
</tr>
<tr>
<td>4</td>
<td>100 (42)</td>
<td>88 (37)</td>
<td>238</td>
</tr>
<tr>
<td>5</td>
<td>223 (36)</td>
<td>79 (13)</td>
<td>625</td>
</tr>
<tr>
<td>6</td>
<td>117 (24)</td>
<td>151 (32)</td>
<td>478</td>
</tr>
<tr>
<td>7</td>
<td>153 (26)</td>
<td>132 (23)</td>
<td>578</td>
</tr>
<tr>
<td>8</td>
<td>119 (14)</td>
<td>117 (14)</td>
<td>858</td>
</tr>
<tr>
<td>9</td>
<td>93 (15)</td>
<td>136 (21)</td>
<td>640</td>
</tr>
<tr>
<td>10</td>
<td>202 (30)</td>
<td>174 (26)</td>
<td>679</td>
</tr>
<tr>
<td>11</td>
<td>29 (24)</td>
<td>0 (0)</td>
<td>120</td>
</tr>
<tr>
<td>12</td>
<td>64 (16)</td>
<td>112 (27)</td>
<td>409</td>
</tr>
<tr>
<td>13</td>
<td>121 (28)</td>
<td>180 (41)</td>
<td>438</td>
</tr>
<tr>
<td>14</td>
<td>106 (20)</td>
<td>190 (37)</td>
<td>519</td>
</tr>
<tr>
<td>15</td>
<td>204 (33)</td>
<td>57 (9)</td>
<td>626</td>
</tr>
<tr>
<td>16</td>
<td>410 (42)</td>
<td>223 (23)</td>
<td>969</td>
</tr>
<tr>
<td>17</td>
<td>193 (22)</td>
<td>209 (25)</td>
<td>867</td>
</tr>
<tr>
<td>18</td>
<td>115 (20)</td>
<td>138 (25)</td>
<td>561</td>
</tr>
</tbody>
</table>
Table 3.2: Comparison between observed (row) feeding, rumination and other behaviour (others) and unadjusted accelerometer-recorded (SensOor, Agis Automatisering, Harmelen, The Netherlands) behaviour (column) per min (% of observed behaviour how it was recorded by accelerometer)

<table>
<thead>
<tr>
<th>Observation</th>
<th>Feeding</th>
<th>Ruminating</th>
<th>Active</th>
<th>Resting</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding</td>
<td>2,488 (93)</td>
<td>61 (2)</td>
<td>139 (5)</td>
<td>4 (0)</td>
<td>2,692 (100)</td>
</tr>
<tr>
<td>Ruminating</td>
<td>768 (32)</td>
<td>1,212 (51)</td>
<td>352 (15)</td>
<td>55 (2)</td>
<td>2,387 (100)</td>
</tr>
<tr>
<td>Others</td>
<td>1,400 (27)</td>
<td>549 (11)</td>
<td>2,236 (43)</td>
<td>988 (19)</td>
<td>5,173 (100)</td>
</tr>
<tr>
<td>Total</td>
<td>4,656</td>
<td>1,822</td>
<td>2,727</td>
<td>1,047</td>
<td>10,252</td>
</tr>
</tbody>
</table>
Table 3.3: Test characteristics (95% CI) of an ear tag-attached accelerometer (SensOor, Agis Automatisering BV, Harmelen, The Netherlands) to monitor feeding and rumination in feedlot cattle adjusted for clustering within steer

<table>
<thead>
<tr>
<th>Behaviour (10,252 min)</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV(^1)</th>
<th>NPV(^2)</th>
<th>CCC(^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeding (2,690 min)</td>
<td>93 (91-94)</td>
<td>70 (65-75)</td>
<td>54 (48-59)</td>
<td>97 (95-97)</td>
<td>0.75 (0.61-0.84)</td>
</tr>
<tr>
<td>Rumination (2,462 min)</td>
<td>48 (35-63)</td>
<td>94 (91-95)</td>
<td>66 (57-74)</td>
<td>87 (84-91)</td>
<td>0.41 (0.20-0.58)</td>
</tr>
<tr>
<td>One-minute filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeding (2,690 min)</td>
<td>95 (93-96)</td>
<td>76 (69-81)</td>
<td>60 (54-65)</td>
<td>98 (97-98)</td>
<td>0.79 (0.61-0.85)</td>
</tr>
<tr>
<td>Rumination (2,462 min)</td>
<td>49 (34-64)</td>
<td>96 (94-98)</td>
<td>78 (69-85)</td>
<td>88 (82-91)</td>
<td>0.44 (0.23-0.60)</td>
</tr>
</tbody>
</table>

\(^1\)Positive predictive value

\(^2\)Negative predictive value

\(^3\)Concordance correlation coefficient
Figure 3.1: Number of minutes that individual steers spent a) feeding and b) ruminating during 1 h recorded by observers (y) and the accelerometer (x). Note that individual steers are represented in various shapes and colors.
3.2 Evaluation of a system for monitoring individual feeding behaviour and activity in beef cattle

3.2.1 Abstract

Behavioural observations are important to detect illness in beef cattle. However, traditional observation techniques are time and labour intensive and may be subjective. The objective was to validate a system for monitoring individual feeding behaviour and activity in beef cattle (FEDO; Fedometer, ENGS, Rosh Pina, Israel). Sixteen steers (initial BW ± SD = 326 ± 46 kg) were fitted with data loggers (FEDO) on their left front leg and housed in a pen with a feedbunk equipped with an antenna emitting an electromagnetic field (every 8 s) that extended 30 ± 2 cm in front of the feedbunk. Every 6 min, FEDO wirelessly transmitted (1) binary data (presence at the feedbunk, yes/no; lying, yes/no; change from standing to lying, yes/no) and (2) counts of steps and electromagnetic field detection to a receiver connected to an on-farm computer. Feedbunk attendance (duration and frequency of visits) measured by FEDO was compared to live observations (27 observations lasting between 72 and 240 min; mean 126 min). Lying time and frequency of lying bouts were compared to previously validated accelerometers fitted to the hind leg (10 steers equipped for 10 to 12 d; HOBO, Onset Computer Corporation, Pocasset, MA, USA). Step counts were compared to video recordings (15 observations for 6-min intervals in 6 steers). Concordance correlations (CCC), accounting for repeated measures and limit of agreement, were computed. Comparison between FEDO and observed time at the feedbunk yielded a CCC of 0.98 (95% CI: 0.97-0.99). All 68 observed plus 4 additional feeding events were recorded by
FEDO. Lying time measured by HOBO and FEDO were highly correlated (CCC = 0.98, 95% CI: 0.97-0.99). However, frequency of lying bouts measured by FEDO was only moderately correlated to HOBO (CCC = 0.71, 95% CI: 0.63-0.77); FEDO underestimating the number of lying bouts (on average, 0.4 less bouts per 6 h). Step count by FEDO was moderately to highly correlated to video observations (CCC = 0.75, 95% CI: 0.49-0.89). In conclusion, the FEDO system accurately measured feedbunk visit frequency and duration, lying time and number of steps, although it underestimated the frequency of lying bouts.

3.2.2 Introduction

Feeding behaviour and activity are frequently monitored to evaluate health status of beef cattle; animals are considered ill when they are off feed or have decreased activity (Weary et al., 2009). Traditionally, such monitoring has been solely based on visual observation, although it is time- and labour-intensive, and may be subjective (Weary et al., 2009).

Various automated systems for monitoring cattle feeding behaviour and activity have been developed (Theurer et al., 2013a). These systems collect data continuously and eliminate potential observer bias (Weary et al., 2009). For example, feedbunk units of the Growsafe system (Growsafe Systems Ltd, Airdrie, AB, Canada) continuously measure individual feeding frequency, duration and intake (Wolfer et al., 2015b). Additionally, various accelerometers can accurately measure activity (i.e. standing and walking) and lying behaviour (Robert et al., 2009; Mattachini et al., 2013).
Recently, a system measuring both cattle individual feeding behaviour (i.e. bunk visit frequency and duration) and activity (i.e. lying time, number of lying bouts and numbers of steps) has been marketed (fedometer [FEDO] system, ENGS, Rosh Pina, Israel). This system uses a data logger attached to the front leg that, in addition to monitoring activity, detects the presence of cattle at the feedbunk. Combining both behaviours in one system may provide a more accurate assessment of the true health status (Theurer et al., 2013a) and be more cost efficient. However, evaluation of the accuracy of the system has not been reported.

The objectives of this study were to determine accuracy of FEDO system to measure: (1) feedbunk attendance (duration and frequency of visits) compared to live observations; (2) lying time and frequency of lying bouts compared to a previously validated accelerometer; and 3) step counts compared to video recordings.

3.2.3 Materials and Methods

This study was conducted at the Agriculture and Agri-Food Canada, Lacombe Research Centre (Lacombe, AB, Canada) during August 2013. All procedures were reviewed and approved by the University of Calgary Animal Care Committee (AC13-0104).

Sixteen Hereford x Angus steers (initial BW ± SD = 326 ± 46 kg) from the Lacombe Research Centre beef herd were used. Steers were housed in an outdoor dirt floor pen (60 x 60 m) topped with wood shaving. They had ad libitum access to fresh water and were slick-bunk fed with 100% barley silage once daily at 0900 h.
At the beginning of the study, the outer wall of the 55 m feedbunk was equipped with an antenna (ENGS, Rosh Pina, Israel) that emitted an electromagnetic field (every 8 s) that extended 30 ± 2 cm from the feedbunk (Figure 3.2). Each steer also had a FEDO data logger strapped to the distal lateral aspect of their left metacarpus. This data logger had a rigid plastic housing of 68.8 x 50.7 x 26.5 mm and weighed 75 g. It measured acceleration (g) in the x, y and z-axes and also detected the electromagnetic field emitted by the antenna installed at the feedbunk. Every 6 min, the data logger wirelessly transmitted (1) binary data (presence at the feedbunk, yes/no; lying, yes/no; change from standing to lying, yes/no) and (2) counts of steps and electromagnetic field detection, to a receiver that was connected to an on-farm computer via an electric cable. Proprietary software (ENGS, Rosh Pina, Israel) converted (1) counts of electromagnetic field detection into feedbunk visits duration and frequency (visits < 5 min apart were defined as a single visit by this software) and (2) g-force readings into lying time, number of lying bouts and number of steps.

To evaluate the accuracy of the FEDO system for measuring time at the feedbunk and number of feedbunk visits, 2 trained observers recorded feedbunk attendance of steers during 27 observation periods lasting between 72 and 240 min (mean 126 min). Observation periods were performed over 11 d between 0430 and 2200 h. During each period, 2 observers randomly selected 2 steers and recorded the start and finish of feedbunk visits, defined as a steer having its head on top of the feedbunk, with the neck between the chest and neck rail. Inter-observer variability was tested prior to the study and twice during the study (r = 0.99). The distance of the electromagnetic field emitted...
by the antenna (30 ± 2 cm) was verified prior to the study and weekly during the study period.

To determine if lying time and lying bout frequency measured by the FEDO system were accurate, accelerometers previously validated for measuring lying behaviour in cattle (HOBO; HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA, USA) (Ito et al., 2009; Bonk et al., 2013) were installed on 10 steers. These devices were programmed to record g-force on the x, y and z-axes at 1-min intervals and were attached to the left hind leg above the fetlock, as described (Ito et al., 2009). The logger’s memory of 64 kB had the capacity to record 21,800 three-dimensional data points (Moreau et al., 2009). After 10 d (5 steers) or 12 d (5 steers) of data collection, HOBO were removed and stored data were downloaded. Onset HOBOware software (Onset Computer Corporation, Bourne, MA, USA) was used to convert g-force readings into degrees of tilt. Macros in Microsoft Excel (Excel version 14.4.1, Microsoft, Redmond, WA, USA) translated degrees of tilt into lying time and number of lying bouts.

To evaluate the accuracy of step counting by the FEDO system, the pen was equipped with a video surveillance system consisting of 8 infrared day/night varifocal cameras (SONY Color CCD, Tokyo, Japan) and a recording computer. During 6-min video recordings (n=90), 1 observer counted steps (forward or backward movement on left front leg) on 6 randomly selected steers.

In this study, behaviours were recorded in various intervals. Therefore, time at the feedbunk, frequency of feedbunk visits, and number of steps were summarized by observation periods (varying in time). Lying time and number of lying bouts were
summarized by 6-h periods. Number of steps was log transformed to achieve normal distribution. The R (R Foundation for Statistical Computing, Vienna, Austria) package CCRM was used to calculate concordance correlation coefficients (CCC) adjusted for repeated longitudinal observations on lying time, number of lying bouts, number of steps and feeding time (Carrasco et al., 2013). All other statistics were performed using Stata version 13.1 (StataCorp, College Station, TX, USA). Residuals of paired measures were represented in Bland and Altman graphs (Bland and Altman, 2010).

3.2.4 Results

During the 27 observation periods, 68 feedbunk visits lasting 2 to 155 min (mean 25 min ± SD 21 min) were observed. On average, observers recorded 1.4 (SD 0.6) feedbunk visits per steer during each observation period. In comparison, the FEDO system recorded 72 feedbunk visits with an average of 1.5 (SD 0.6) visits per steer per observation period. The FEDO system detected all 68 observed feedbunk visits, but also detected 4 additional visits not classified as feedbunk visits by observation (i.e. neck was not between the rails). Observed time at the feedbunk was on average 1.1 min shorter than feedbunk time recorded by FEDO (Figure 3.3). Concordance correlation between FEDO and observed time at the feedbunk was 0.98 (95% CI: 0.97-0.99; Table 3.4).

Data for HOBO and FEDO were available for 10 steers and a total of 259 complete 6-h periods. Due to a power outage, 7.5 d of FEDO records were lost. The average lying time per 6 h recorded by HOBO was 171 min (SD 114 min) with 2.5 (SD 1.7) lying bouts, whereas FEDO recorded an average of 172 min (SD 114 min) of lying with 2.1 (SD 1.7) lying bouts per 6 h. The CCC between the 2 accelerometers was 0.98
(95% CI: 0.97-0.99) for lying time and 0.71 (95% CI 0.63-0.77) for lying bouts (Table 3.4).

Based on video observations, steers took on average 11 steps per 6 min (range 0-189), whereas the FEDO system recorded 16 steps (range 0-362; Figure 3.3). Concordance correlation between observed and FEDO recorded number of steps was 0.75 (95% CI: 0.49-0.88).

3.2.5 Discussion

Compared to the dairy industry, few monitoring systems have been validated in beef cattle. Notwithstanding, automated real-time monitoring of beef cattle behaviour is crucial for farm expansion, especially with increasing labour costs (Wagner et al., 2014). In the present study, we evaluated a new system (FEDO) that can measure both feeding behaviour and activity of beef cattle. This system accurately measured feedbunk visit frequency and duration, lying time and number of steps. However, frequency of lying bouts measured by this system was slightly underestimated in comparison to a previously validated accelerometer.

Although the FEDO system detected proximity to the feedbunk and not active feeding, this system accurately measured feeding behaviour. The measured time spent at the feedbunk was highly correlated to observations and only 4 additional feeding events were monitored by FEDO. This high accuracy was consistent with a report that most feedbunk visits (i.e. 89%) by feedlot steers were associated with active feeding (Schwartzkopf-Genswein et al., 1999). Although the accuracy of feedbunk visit frequency measurement could be further improved by using head-locking systems (Bach
et al., 2004), the FEDO system allowed all cattle to feed simultaneously, which reflects more natural cattle behaviour (Rook and Huckle, 1995).

The FEDO system accurately measured the lying time but underestimated the frequency of lying bouts. This underestimation can be explained by the long sampling interval for lying behaviour (i.e. 6 min). Indeed, sampling intervals > 2 min have previously been described as inadequate to predict the number of lying bouts (Mattachini et al., 2013). Undeniably, with a long sampling interval, some short lying bouts will not be recorded. Accurate measurement of lying bout frequency can be important. For example, there were more lying bouts in castrated calves given pain medication (flunixin meglumine) compared to castrated calves without pain medication (Mintline et al., 2014).

The relatively high correlation between step counts measured by FEDO and video observation was not expected. Indeed, other validated accelerometers (Icetag, IceRobotics, Edinburgh, UK) only provided sensitivities ranging from 0.26 to 0.29, though high specificity (Mattachini et al., 2013). This was attributed to the higher sampling frequency reported by the FEDO manufacturer i.e. 1000 Hz versus the 8 Hz reported for the Icetag (Mattachini et al., 2013). Therefore, the FEDO system can be useful to detect changes in the number of steps, which has been associated with oestrus (Firk et al., 2002), lameness (Alsaad et al., 2012), or respiratory disease (Hanzlicek et al., 2010).

In addition to simultaneously monitoring 2 behaviours (i.e. feeding and activity), this system transmits data wirelessly, enabling real-time monitoring of behaviours and overcoming the limited storage capacity of previously validated systems. For example, in the present study, the HOBO loggers had to be removed and replaced after 12 d due to
limited storage capacity (associated with a 1-min transmission interval). However, it was noteworthy that we lost 7.5 d of data due to inadequate storage on the on-farm computer, which could have been avoided with data storage in the data logger or a server-based automated data storage.

In conclusion, the FEDO system accurately measured feedbunk visit frequency and duration, lying time and number of steps, although it underestimated lying bout frequency. Therefore, it could be used in research settings and field applications to accurately monitor feeding and activity in beef cattle.
Table 3.4: Concordance correlation coefficient (CCC) adjusted for repeated longitudinal measures comparing FEDO (Rosh, Pina, Israel) and 1) live observations (OBS), 2) HOBO, and 3) video observations.

<table>
<thead>
<tr>
<th>Behaviour</th>
<th>n</th>
<th>Method</th>
<th>CCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunk attendance</td>
<td>68</td>
<td>OBS</td>
<td>0.98 (0.97-0.99)</td>
</tr>
<tr>
<td>Lying time</td>
<td>259</td>
<td>HOBO</td>
<td>0.98 (0.97-0.99)</td>
</tr>
<tr>
<td>Lying frequency</td>
<td>259</td>
<td>HOBO</td>
<td>0.71 (0.63-0.77)</td>
</tr>
<tr>
<td>Step count</td>
<td>94</td>
<td>Video</td>
<td>0.75 (0.49-0.89)</td>
</tr>
</tbody>
</table>
Figure 3.2: FEDO logger recognizes electromagnetic field transmitted by antenna.
Figure 3.3: Difference between FEDO (Rosh, Pina, Israel) and a) feeding behaviour recorded with live observations; b) lying time during 6-h periods recorded by validated accelerometers (HOBO); and c) number of steps counted with video observations in 6-min observations
Chapter Four: EVALUATING THE COST IMPLICATIONS OF A RADIO FREQUENCY IDENTIFICATION FEEDING SYSTEM FOR EARLY DETECTION OF BOVINE RESPIRATORY DISEASE IN FEEDLOT CATTLE
4.1 Abstract

New technologies to identify diseased feedlot cattle in early stages of illness have been developed to reduce costs and welfare impacts associated with bovine respiratory disease (BRD). However, the economic value of early BRD detection has never been assessed. The objective was to simulate cost differences between two BRD detection methods during the first 61 days on feed (DOF) applied in moderate- to large-sized feedlots using an automated recording system (ARS) for feeding behaviour and the current industry standard, pen-checking (visual appraisal confirmed by rectal temperature). Economic impact was assessed with a cost analysis in a simple decision model. Scenarios for Canadian and US feedlots with high- and low-risk cattle were modeled, and uncertainty was estimated using extensive sensitivity analyses. Input costs and probabilities were mainly extracted from publicly accessible market observations and a large-scale US feedlot study. In the baseline scenario, we modeled high-risk cattle with a treatment rate of 20% within the first 61 DOF in a feedlot of > 8,000 cattle in Canada. Early BRD detection was estimated to result in a relative risk of 0.60 in retreatment and 0.66 in mortality compared to pen-checking (based on previously published estimates). The additional cost of monitoring health with ARS in Canadian dollar (CAD) was 13.68 per steer. Scenario analysis for similar sized US feedlots and low-risk cattle with a treatment rate of 8% were included to account for variability in costs and probabilities in various cattle populations. Considering the cost of monitoring, all relevant treatment costs and sale price, ARS was more costly than visual appraisal during the first 61 DOF by CAD 9.61 and CAD 9.69 per steer in Canada and the US, respectively. This cost
difference increased in low-risk cattle in Canada to CAD 12.45. Early BRD detection with ARS became less expensive if the costs for the system decreased to less than CAD 4.06/steer, or if the underlying true BRD incidence (not treatment rate) within the first 61 DOF exceeded 47%. The model was robust to variability in the remaining input variables. Some of the assumptions in the baseline analyses were conservative and may have underestimated the real value of early BRD detection. Systems such as ARS may reduce treatment costs in some scenarios, but the investment costs are currently too high to be cost-effective when used solely for BRD detection compared to pen-checking.

4.2 Introduction

Despite various control efforts, bovine respiratory disease (BRD) continues to have tremendous impacts on economics and animal welfare in the feedlot industry (USDA, 2013a). A feedlot with a 14.4% BRD treatment rate per feeding period was estimated to lose approximately USD 14,000 per 1000 incoming cattle, not including feed costs before the death of calves, labour and associated handling costs (Snowder et al., 2006). However, not all incoming cattle are at the same risk for developing BRD; feedlot personnel (pen-checkers) classify cohorts into risk categories to choose an arrival protocol that includes or excludes antimicrobial metaphylaxis (USDA, 2013b). Once cattle are affected by BRD, they show clinical signs late in the disease process (Timsit et al., 2011a), and sensitivity and specificity of visual appraisal (pen-checking) confirmed with rectal temperature are low (White and Renter, 2009). Consequently, many cattle are treated unnecessarily, although performance is reduced due to missed cases and late
treatment of BRD. In contrast, early detection of BRD results in higher treatment efficacy (Ferran et al., 2011) and lower mortality (Janzen et al., 1984).

One method of early BRD detection is monitoring feeding time and intake. A study that used feeding behaviour to predict BRD reported identification of sick cattle on average 4 d prior to pen-checker identification (Quimby et al., 2001). However, the economic value of early BRD detection has never been assessed. Therefore, the objective of this study was to assess the economic value (in Canadian dollars - CAD) of early BRD detection using automated recording systems (ARS) in comparison to pen-checking during the first 61 days on feed (DOF). We hypothesized that ARS would be the economically preferred strategy of BRD detection during the first 61 DOF.

4.3 Methods

This economic modeling study was conducted following Canadian guidelines for economic evaluation of health technologies (CADTH, 2006). The study extracted data from existing literature and databases; therefore, no animal care approval was required.

The economic impact of early BRD detection with ARS in comparison to pen-checking was assessed using a deterministic model based on costs and revenues of finishing cattle in high-risk (treatment rate during feeding period 20%, baseline scenario) and low-risk (treatment rate during feeding period 8%) cohorts. General management practices were identical, but disease detection (decision nodes) during the first 61 DOF was based on either the traditional method of pen-checking, or ARS detecting feeding behaviour changes 4 d prior to pen-checker identification (Quimby et al., 2001). After 61
DOF, disease detection was done with pen-checkers in both decision nodes. The economic impact was calculated as the difference in net-benefit [(slaughter revenues minus expenditures; (Cernicchiaro et al., 2013)] between pen-checking and ARS expressed in CAD per calf at the end of the feeding period. The simulation was performed from the perspective of a mid-size to large North American feedlot operation with a one-time capacity of > 8,000 head (to account for the size of the investment).

### 4.3.1 BRD detection methods

Two disease detection methods were compared during the first 61 DOF, the high-risk period for BRD (Babcock et al., 2010):

1) Pen-checking was based on health evaluations done twice daily during the high-risk period. Feedlot personnel identified sick cattle according to their appearance in the feedlot pen (visual appraisal), with a follow-up chute assessment and treatment. Sensitivity and specificity of clinical illness scoring has been estimated at 82% (range: 55-96%) and 95% (range: 81-97%), respectively, in calves with 5% of the lung affected (Amrine et al., 2013).

2) Individual feeding behaviour monitoring identified sick cattle based on changes in feeding behaviour. When a steer was present at an individual feeding node, ARS (Growsafe Ltd., Airdrie, AB, Canada) scanned its unique radio-frequency ear tag in 1-s intervals, enabling calculation of feeding time. Concurrently, an embedded scale measured feed disappearance. Detailed description and validation of the system has been published (Schwartzkopf-Genswein et al., 2011). Differences in feeding time led to
detection of cattle approximately 4 d before clinical signs of sickness appeared (Quimby et al., 2001). Early detection of BRD resulted in better response rate to treatment (Ferran et al., 2011) and lower mortality (Janzen et al., 1984). To our knowledge, sensitivity and specificity estimates for ARS have until now only been calculated on the basis of pen-checking, which is an imperfect test (Quimby et al., 2001).

4.3.2 Estimating true incidence

Due to low sensitivity and specificity, using pen-checking to determine the true disease status will not provide a good estimate of the BRD incidence in post-weaned calves. The most likely true incidence of BRD was therefore calculated using Bayesian approaches in WinBUGS 1.4.3 (Lunn et al., 2000) for the two risk categories with 20% (± 2% SEM) and 8% (± 1% SEM) apparent incidence (treatment rate), respectively (USDA, 2013a). The equation to calculate true incidence was extracted from a previous report (Speybroeck et al., 2013). Sensitivity and specificity estimates for visual appraisal were obtained from a recent publication and plugged into the equation with the full range for cattle with > 5% lung tissue affected (Amrine et al., 2014).

4.3.3 Design

Cattle populations entering the feedlot were simulated in a decision tree, using TreeAge Pro (TreeAge Software Inc., Williamstown, MA, USA). Cattle could either develop BRD or not, and would be detected as having BRD in the two detection strategies based on the test characteristics of the monitoring methods, as noted above.
Cattle identified with either method could be true positive (actually sick) or misclassified (false positive), whereas undetected cattle could either be truly healthy, sick (false negative) or die. True positive cattle could recover, die, develop chronic disease, or be retreated if the first treatment was not effective (Figure 4.1).

In the baseline scenario, we modeled high-risk cattle, arriving with a bodyweight of < 318 kg that were assumed to have a BRD treatment rate of 20% during the feeding period (baseline scenario). In scenario analyses, we also modeled low-risk cattle (≥ 318 kg) that were assumed to have a treatment rate of 8% during the feeding period (USDA, 2013a).

Probabilities for treatment, retreatment, chronicity, and mortality for the two BRD risk scenarios were extracted from a large-scale feedlot study (USDA, 2013a). Some probability estimates within a population in this study did, however, not sum to one. Those specific categories were discussed with experts (industry expert representing the Academy of Veterinary Consultants (AVC)) and converted to mutually exclusive probabilities. Cattle that responded to one treatment, but did not reach the target end weight for other reasons than BRD were defined as chronic; the chronic population was therefore subtracted from the probability to recover. The 6 and 10% of cattle in the first and second retreated group that were not assigned to one category, were assumed to be distributed similarly to the population with known estimates (Table 4.1).

If no previously published data were available, values were based on consultation with experts in the feedlot industry (Veterinary Agri-Health Service (VAHS), Airdrie, AB, Canada and Namaka Farms Inc, Strathmore, AB, Canada). Costs and slaughter
revenues were calculated for cattle that were never treated, treated once, twice, ≥ three times, dead and chronic cattle.

4.3.4 Costs

All costs and revenues were converted to and reported in Canadian dollars (CAD) (http://www.bankofcanada.ca/rates/exchange/daily-converter/; access date 2014-06-23) and were extracted from recent publications or public releases of market observations over the past 5 y (Table 4.2). Costs for treatment included chute charge (pen-checking, treating animals) and drug costs. Average daily gain (ADG) was included as a performance measure to account for downstream effects of disease. Yardage costs included labour, equipment, utility and fuel costs and were calculated per cattle DOF (Jensen and Mark, 2010). Feeding costs were calculated with the variable feed costs per gain. Costs were included in the model as: 

\[ \text{arrival weight} \times \text{feeder cost} + \text{treatment costs} + (\text{daily yardage} + \text{feed cost per gain} \times \text{ADG}) \times \text{DOF}. \]

The cost of ARS was estimated based on an assumed life expectancy of 10 y, with the system being used for BRD detection in 750 calves/y (one pen with 250 calves, 3 runs/y) semi-annually. The estimated maximum capacity for one ARS feed bunk is eight feedlot cattle (Gonzalez et al., 2008a) resulting in approximately 31 such feed bunks in a pen with a 250 cattle capacity. Purchasing cost was estimated at CAD 4,000 per node. The annuity factor was 7.7217 (Bank of Canada) and was included to account for discounting over a 10-y interval (Drummond, 2005). Annual maintenance and program costs of CAD 100 per node were included in addition to purchase costs (personal
communication Namaka Farms Inc., 2014). Total costs per calf for monitoring using ARS were therefore CAD 13.68 for the first 61 DOF. Pen-checking costs remained the same in both the ARS and pen-checking decision node.

4.3.5 Revenue

To assess the economic value of ARS in comparison to pen-checking, the outcome was selling price per kg live weight as the most useful outcome for feedlot operators. Average live price for steers was CAD 145.32 per 45.4 kg in Alberta in April 2014; the range over the past 5 y was CAD 92.71-145.32 (Canfax, 2014). The costs for the true healthy population were used for the false positive population, except this also included treatment costs. Alternatively, estimates from the first treated true positive population that recovered were included in the false negative population arm, excluding treatment costs.

The modeled time horizon for the study was set to one feeding period; however, we simulated that cattle were to remain in the pen for 61 DOF to fully utilize the ARS for multiple high-risk populations within one feeding season. Revenues were calculated as:

\[
(ADG \times DOF + \text{arrival weight}) \times \text{average live wt price over the past 5 y for steers slaughtered during April in Alberta.}
\]

The outcome was calculated by subtracting all costs from the slaughter revenue of cattle in the specific treatment arms.
4.3.6 Comparators

The tree compared pen-checking and ARS in terms of BRD detection. Both BRD identification arms were identical, except for different retreatment rates and mortalities if ARS was used. As no information was available on true sensitivity and specificity of ARS systems, identical estimates to pen-checking were used in the baseline scenario.

4.3.7 Model structure

The overall costs of the two systems for BRD detection were estimated using decision analysis (Dijkhuizen et al., 1995). Only costs and benefits that differed between the decision nodes were included in the analysis. The analysis was performed on an individual-animal level. Arriving calves had probabilities for treatments, retreatments, chronicity and death (which affected their ADG).

Since calves identified earlier in the disease process with ARS would be less likely to relapse, the relative risk for multiple treatments was 0.60 when ARS was used as an identification tool (Ferran et al., 2011). The relative risk or 0.66 for mortality in the ARS arm was extracted from a Canadian BRD infection trial (Janzen et al., 1984).

The baseline scenario was modeled from the perspective of large Canadian feedlot operations (> 8,000 cattle one-time capacity) with a 20% incidence of BRD treatment during the first 61 DOF; the average treatment incidence for high-risk cattle was based on arrival weight (< 318 kg) in Northern American feedlots (USDA, 2013a).

Probabilities, costs and revenues were entered with a range to enable sensitivity analysis and to account for variability among feedlots (Table 4.1, Table 4.2). The point
estimates of costs and revenues for the baseline scenario were the most recent market observations for the population of high-risk cattle in Alberta (Canfax, weeks 12 and 13, 2014).

4.3.8 Uncertainty and Variability

Univariate sensitivity analysis was used to account for variability in incidence, treatment costs, feeding costs, selling prices, and relative risks for death and retreatments in the ARS arm. The variability of input variables was based on the 95% CI if not specified otherwise. A tornado diagram was created to present the impact of lowering or raising variable estimates.

Threshold analysis was accomplished to identify the economic impact if the cost for ARS or the true BRD incidence were changed.

4.3.9 Scenario analyses based on cattle type

Incoming cattle populations were simulated with various characteristics to account for differences in 1) costs and revenues in US feedlots (USDA-AMS, March 2014), and 2) lower risk of BRD treatment (apparent incidence) during the feeding period (Table 4.3). More scenario analyses were performed to account for the uncertainty and lack of independence between sensitivity and specificity estimates for ARS and pen-checking. Probabilities for sensitivity and specificity were extracted from published reports (Table 4.4).
### 4.3.10 Assumptions and applications

The simulation kept cattle in the pen with the ARS for 61 DOF, which includes the period when most BRD cases occur for all risk categories (Babcock et al., 2010). Only treatments with BRD as the primary illness were considered for this analysis. The estimates were largely extracted from a wide range feedlot study in the US assuming similar estimates for Canadian feedlots (USDA, 2013a). Costs and revenues were calculated for a steer population and extracted from Canadian sources to reflect the baseline scenario in the Canadian feedlot industry.

The ARS system was applied for early BRD detection 6 mo/y. Revenues and costs for the remaining 6mo/y were not included in this simulation. Despite lower labour costs for disease detection, costs for pen-checking were not reduced if ARS was used, due to additional labour needed for feed bunk maintenance and dealing with erroneous RFID tags. Additionally, pulling sick cattle was still the responsibility of pen-checkers.

### 4.3.11 Model validation

The model outcomes in the pen-checking arm were compared with actual feedlot data (Feedlot Protocol Impact Calculator V.5.0, Bruce Viney, Government of Alberta, Agriculture and Rural Development Alberta, Edmonton, AB, Canada) for external validity. One-way sensitivity analyses on all variables were performed to assess face validity and technical accuracy. Ultimately, the model was validated by reviews of experts in the fields of economic evaluation and production animal health. Differences between the two arms of the decision tree were removed to calibrate the model and
identify potential typing or calculation errors; the expected outcome in this step was, therefore, a 0 net-benefit difference.

4.4 Results

The estimated true incidence of BRD in the baseline scenario in the first 61 DOF was 14% (± 7%), whereas in a scenario with an 8% treatment rate the true incidence was 4% (± 3%). In both, the Canadian and US high-risk scenarios, pen-checking was the economically preferred strategy in identifying sick cattle, as it was associated with lower costs of CAD 9.61 and CAD 9.69 per calf, respectively. For low-risk steers, pen-checking was less costly by CAD 12.45 in a Canadian feedlot.

4.4.1 Uncertainty analysis

The tornado diagram (Figure 4.2) reflects the ability of certain variables to drive net-benefit difference in Canadian high and low-risk cattle. The cost differences between pen-checking and ARS ranged from CAD 5.58 to 8.58 per steer if sensitivity and specificity of both systems were changed to previously published estimates (Table 4.4). Although pen-checking remained less costly even when sensitivity and specificity of pen checking were lowered to 62 and 63%, respectively, the cost difference between the two systems was lower (Table 4.5).

In the baseline high-risk scenario, ARS became less costly if the price for the system per steer was below CAD 4.06 or CAD 4.85 in the US scenario from CAD 13.70,
whereas in the low-risk scenario the costs of ARS would have to be below CAD 1.24 per steer.

If the true incidence of BRD changed from 14%, as presented in the baseline scenario, to > 47% in Canada or > 48% in the US, ARS would also become the economically superior disease detection strategy for high-risk cattle (Figure 4.2). Pen-checking was the preferred method of BRD detection otherwise and was robust to variations in the remaining variables in one-way sensitivity analyses.

4.5 Discussion

To our knowledge, this is the first study that estimated probability changes and costs associated with early BRD detection using an ARS based on changes in feeding behaviour. The present study demonstrated that despite low test accuracy, pen-checking, with a higher net-benefit of CAD 9.61 and CAD 9.69 per animal, was still the cheapest method of disease detection in feedlots in Western Canada and the US respectively. However, this simulation is based on current treatment and arrival protocols, where feedlot operators use antimicrobial treatment on arrival in foreseen high-incidence cohorts. This strategy to reduce or stop high BRD incidence is used in 93% of US feedlots with a capacity of > 8,000 cattle that treat 41% of the incoming population with an arrival weight of < 318 kg (USDA, 2013b). With increasing concern of antimicrobial resistance (Klima et al., 2014), and a potential link to the antibiotic use in livestock, the feedlot industry is being pressured to decrease antimicrobial use (WHO, 2012). Following the European model (EMA, 2012) extensive use of antimicrobials will become
harder to justify and new approaches to avoid BRD outbreaks or limit the health impacts need to be considered by the industry. Early identification is crucial for treatment efficacy (Cusack et al., 2003) and was shown to decrease retreatment rates (Ferran et al., 2011) and mortality (Janzen et al., 1984). Using an automated feeding behaviour recording system (ARS), one study ($n = 213$) predicted 82% of pen-checker identified steers 5 d earlier than pen-checking and identified 22% of visually healthy steers as suspicious (Wolfger et al., 2015b).

The price of the alternative detection method, ARS, was economically highly influential in the modeled scenario, such that a drop in per-animal costs to less than CAD 4.06 in the baseline scenario from CAD 13.68 would result in ARS being the more cost-effective detection method. With an increasing number of monitoring devices and ever evolving technology, such systems will likely become more affordable. In addition to early BRD detection, the specific monitoring system tested in this scenario can be used for other purposes measuring feed efficiency and its four related traits (namely ADG, dry matter intake, feed conversion ratio, and residual feed intake) for in-house studies (Wang et al., 2006; Durunna et al., 2011), which have not been taken into consideration in this study. Feedlot operations using this technology should also be aware of potential snow accumulation, increasing the workload on specific days and technical errors that require labour to follow-up. Additionally, bunk dimensions could be inappropriate for smaller newly weaned calves resulting in additional costs for adjusting easy access for small-framed calves.

Surprisingly, changing sensitivity and specificity values for ARS and pen-checking did not change the dominance of pen-checking. In-depth studies regarding
detection performance of ARS and effects of early BRD detection on performance of feedlot cattle (ADG, yielding, grading, etc.) still need to be addressed to derive more accurate conclusions regarding health-monitoring systems. Additionally, within the group of misclassified cattle, the effect on performance is still unclear. Specifically, cattle subclinically affected by BRD might not meet the clinical criteria for a treatment, although performance differences indeed can be expected, as pointed out in studies using lung lesion scoring at harvest (Gardner et al., 1999; Schneider et al., 2009). In the present study, this knowledge gap most likely resulted in underestimation of the performance of ARS in comparison to pen-checking. The present study did not factor in reduced labour costs if an alternative health monitoring system was used, because labour would be shifted towards error messages. Furthermore, weather-related management could shift when and where extra labour was required (e.g. shovelling snow out of feedbunk).

Difficulties in recruiting qualified feedlot personnel, however, could influence management decisions to buy ARS for the use of early BRD detection. Similarly, further development of the ARS used as an example in this study or other ARS technology might overcome such challenges and result in an actual reduction of labour costs. However, the daily per calf labour costs were included as 35% of the yardage costs (Canadian scenario: CAD 0.09). Those costs include pen-checkers, administration, feed truck drivers, other labour and management costs. It is therefore highly unlikely that a change in labour costs would affect the current outcome.

In a review of BRD effects on performance in feedlot cattle, we decided to choose a recent study with a high sample size to extract the values for ADG (Cernicchiaro et al., 2013). Although most studies agreed on decreased performance if cattle were treated,
several publications discussed a compensational weight gain of cattle treated only once (Gifford et al., 2012). However, the lack of a difference between ADG in cattle without treatment and with a single treatment would not change the fact that pen-checking is currently more cost-efficient compared to ARS.

Similar to other economic evaluations, results were inherently limited by data availability. A gold standard definition for BRD has yet to be developed. Further, blinded randomized controlled trials using various health evaluation methods would help identify the true economic benefit of early BRD detection. However, due to animal health and welfare concerns, this has not been accomplished. Consequently, with our conservative estimates, we might have underestimated the real value of early disease detection with ARS.

This study presented various scenarios accounting for differences in management practices between Canada and the US, as well as distinct risk groups of cattle. The model estimates were mostly extracted from large-scale US studies or Canadian databases ensuring a wide generalizability of the results. Additionally, that the main drivers of the difference between ARS and pen-checking were the cost of the system and the incidence of BRD and not revenues or costs associated with growing cattle, needs to be addressed.

4.5.1 Conclusions

Under current feedlot management practices, net-benefits were lower when ARS was used as a tool in BRD detection in comparison to pen-checking in North American
feedlots. Lowering per-calf costs of ARS to CAD < 4.06 or higher BRD incidence (> 47%) would reverse the economic difference, resulting in ARS as the economically superior BRD detection method.
Table 4.1: Probability estimates for steer calves at high-risk of Bovine Respiratory Disease (baseline scenario), extracted from USDA NAHMS Feedlot 2011 study (USDA, 2013a) as calculated with a relative risk of retreatment (0.60) and a relative risk of death in treated steers (0.66) in the automated recording system (ARS).

<table>
<thead>
<tr>
<th></th>
<th>Penchecking</th>
<th></th>
<th>ARS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate</td>
<td>95% CI</td>
<td></td>
<td>Estimate</td>
</tr>
<tr>
<td>Treatment rate(^a)</td>
<td>0.20</td>
<td>0.16 – 0.24</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Death other than BRD</td>
<td>0.003</td>
<td>0.001 – 0.005</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td><strong>First treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovered</td>
<td>0.79</td>
<td>0.77 – 0.81</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>Retreated</td>
<td>0.15</td>
<td>0.11 – 0.19</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td>Chronic</td>
<td>0.02</td>
<td>0.01 – 0.04</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Dead</td>
<td>0.04</td>
<td>0.03 – 0.05</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td><strong>Second treatment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovered</td>
<td>0.67</td>
<td>0.57 – 0.77</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td>Retreated</td>
<td>0.13</td>
<td>0.09 – 0.17</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Chronic</td>
<td>0.06</td>
<td>0.04 – 0.08</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Dead</td>
<td>0.14</td>
<td>0.05 – 0.21</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>≥ Three treatments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovered</td>
<td>0.43</td>
<td>0.32 – 0.54</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Chronic</td>
<td>0.24</td>
<td>0.17 – 0.35</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>Dead</td>
<td>0.31</td>
<td>0.22 – 0.40</td>
<td>0.31</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Threshold analysis: input variability: 0.07 – 0.80
Table 4.2: Production costs, revenues (CAD) and cohort characteristics of a feedlot cattle population at high-risk for bovine respiratory disease (20% treatment rate) in Canada and the United States (US).

<table>
<thead>
<tr>
<th></th>
<th>Base case</th>
<th>Range</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrival weight, kg</td>
<td>255.2</td>
<td>168.2-293.1</td>
<td>Babcock et al., 2009</td>
</tr>
<tr>
<td>Avg. feeder price/45.4 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>159.92</td>
<td>108.96 – 166.80</td>
<td>Canfax, 2014</td>
</tr>
<tr>
<td>US</td>
<td>216.28a</td>
<td>210.85 – 218.67</td>
<td>USDA-AMS, March 2014b</td>
</tr>
<tr>
<td>ARSc, 3*250 calves/y</td>
<td>13.70</td>
<td>Threshold analysis</td>
<td>Namaka Farms Inc., 2014</td>
</tr>
<tr>
<td>Days on feed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>199</td>
<td>183-242</td>
<td>Babcock, 2009</td>
</tr>
<tr>
<td>Canada</td>
<td>250</td>
<td>240- 260</td>
<td>VAHSd, 2014</td>
</tr>
<tr>
<td>Days on feed dead</td>
<td>48</td>
<td></td>
<td>Loneragan et al., 2001</td>
</tr>
<tr>
<td>Yardage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US yard/d</td>
<td>0.22a</td>
<td>± 25%</td>
<td>Cernicchiaro et al., 2013</td>
</tr>
<tr>
<td>Canada/d</td>
<td>0.27</td>
<td>± 25%</td>
<td>VAHSd, 2014</td>
</tr>
<tr>
<td>Feed costs/kg gain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US feed</td>
<td>1.66a</td>
<td>± 25%</td>
<td>70% of COGe, Hughes, 2013</td>
</tr>
<tr>
<td>Canada</td>
<td>1.65</td>
<td>± 25%</td>
<td>Canfax, 2014</td>
</tr>
<tr>
<td>Treatment costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>25.78a</td>
<td>USDA, 2013</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>24.50</td>
<td>± 25%</td>
<td>VAHSd, 2014</td>
</tr>
<tr>
<td>ADG, kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never treated</td>
<td>1.43</td>
<td>± 0.28</td>
<td>Cernicchiaro et al., 2013</td>
</tr>
<tr>
<td>Relative ADG for treatment groups</td>
<td>Base case</td>
<td>Range</td>
<td>Source</td>
</tr>
<tr>
<td>----------------------------------</td>
<td>-----------</td>
<td>--------------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>1</td>
<td>0.95</td>
<td>0.94-0.96</td>
<td>Cernicchiaro et al., 2013</td>
</tr>
<tr>
<td>2</td>
<td>0.92</td>
<td>0.91-0.93</td>
<td></td>
</tr>
<tr>
<td>≥3</td>
<td>0.88</td>
<td>0.87-0.89</td>
<td></td>
</tr>
<tr>
<td>Chronic</td>
<td>0.50</td>
<td></td>
<td>VAHS&lt;sup&gt;d&lt;/sup&gt;, 2014</td>
</tr>
</tbody>
</table>

Live price slaughter/45.4 kg

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>145.32</td>
<td>92.71 – 145.32</td>
<td>Canfax, wk 12 and 13 2014</td>
</tr>
<tr>
<td>US</td>
<td>163.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>152.34-170.88</td>
<td>USDA-AMS, March 2014&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>US dollar converted into CAD, fcana.ca/rates/exchange/daily-converter/, accessed 2014-04-03

<sup>b</sup>http://www.agmanager.info/livestock/marketing/graphs/Cattle/Forecasts/Slaughter%20Prices/sltprfcst.htm, accessed 2014-04-03

<sup>b</sup>Growsafe Ltd., automated feeding behaviour recording system, threshold analysis: CAD 1-13.7

<sup>d</sup>Veterinary Agri-Health Services, Airdrie, AB, Canada

<sup>e</sup>Cost of gain
Table 4.3: Variables that differed from the baseline analysis for cattle at low risk of bovine respiratory disease comparing pen-checking and an automated recording system (ARS). Probabilities extracted from USDA NAHMS Feedlot 2011 study (pen-checking column) and calculated when ARS with lower retreatment and death losses after first treatment was used. Days on feed were extracted from the Veterinary Agri-Health (VAHS) database, ADG from Cernicchiaro et al. (2013).

<table>
<thead>
<tr>
<th>Comment</th>
<th>Pen-checking ARS</th>
<th>ARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment rate</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Death, per 1000</td>
<td>3.00</td>
<td>3.00</td>
</tr>
<tr>
<td>Other than BRD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovered</td>
<td>0.81</td>
<td>0.86</td>
</tr>
<tr>
<td>Retreated</td>
<td>0.13</td>
<td>0.09</td>
</tr>
<tr>
<td>Chronic</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Dead</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Second treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovered</td>
<td>0.62</td>
<td>0.62</td>
</tr>
<tr>
<td>Retreated</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Chronic</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Dead</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>≥ Three treatments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovered</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>Chronic</td>
<td>0.29</td>
<td>0.29</td>
</tr>
<tr>
<td>Dead</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>Days on feed, d</td>
<td>215</td>
<td>215</td>
</tr>
<tr>
<td>VAHS database</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pen-checking</td>
<td>ARS</td>
</tr>
<tr>
<td>--------------------------------</td>
<td>--------------</td>
<td>-----</td>
</tr>
<tr>
<td>ADG, kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never treated</td>
<td>1.48</td>
<td>1.48</td>
</tr>
<tr>
<td>Treated once</td>
<td>1.42</td>
<td>1.42</td>
</tr>
<tr>
<td>Treated twice</td>
<td>1.31</td>
<td>1.31</td>
</tr>
<tr>
<td>Treated ≥3</td>
<td>1.28</td>
<td>1.28</td>
</tr>
<tr>
<td>Arrival weight, kg</td>
<td>350.4</td>
<td>350.4</td>
</tr>
<tr>
<td>Feeder cost, CAD</td>
<td>145.3</td>
<td>145.3</td>
</tr>
</tbody>
</table>
Table 4.4: Input sensitivity (Se) and specificity (Sp) point estimates (%) for detecting bovine respiratory disease in percentage using priors in the Bayesian software WinBUGS (Lunn et al., 2000) with > 5% lung consolidation (Amrine et al., 2013) and extracted from literature to account for uncertainty through scenario analysis.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pen-checking</th>
<th>Automated recording</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Se</td>
<td>Sp</td>
</tr>
<tr>
<td>Baseline</td>
<td>74</td>
<td>89</td>
</tr>
<tr>
<td>2</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
<td>89</td>
</tr>
<tr>
<td>4</td>
<td>62</td>
<td>63</td>
</tr>
<tr>
<td>5</td>
<td>74</td>
<td>89</td>
</tr>
</tbody>
</table>
Table 4.5: Difference in cost between a BRD monitoring strategy involving pen-checking and an automated recording system (ARS), including the impact of varying sensitivity and specificity.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Pen-checking</th>
<th>Se/Sp ARS</th>
<th>Cost difference (CAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High risk</td>
<td>Equal</td>
<td>9.61</td>
<td></td>
</tr>
<tr>
<td>Low risk</td>
<td>Equal</td>
<td>12.45</td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High risk</td>
<td>Equal</td>
<td>9.69</td>
<td></td>
</tr>
<tr>
<td>Se/Sp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>62/63</td>
<td>84/85</td>
<td>5.58</td>
<td></td>
</tr>
<tr>
<td>74/89</td>
<td>83/85</td>
<td>8.58</td>
<td></td>
</tr>
<tr>
<td>62/63</td>
<td>83/85</td>
<td>6.01</td>
<td></td>
</tr>
<tr>
<td>74/89</td>
<td>84/88</td>
<td>8.15</td>
<td></td>
</tr>
</tbody>
</table>
Figure 4.1: Decision tree to assess the difference in net-benefit between automated recording systems and pen-checking for detection of BRD in feedlot cattle.
Figure 4.2: Changes in net-benefit with variability in variables described in Table 4.1 if an automated feeding behaviour recording system (ARS) is used in comparison to pen-checker detection (above 0 means in favor of pen-checker detection). The right vertical line represents the baseline scenario with a net-benefit difference of CAD 9.61 per steer and the bars represent a change between the net-benefit differences when single variables are changed. Bars crossing zero to the left illustrate economic dominance of ARS (left vertical line).
Chapter Five: REVIEW: RECENT ADVANCES IN BOVINE RESPIRATORY DISEASE CONFIRMATION, EARLY DETECTION AND PREDICTION OF UNFAVORABLE OUTCOME IN FEEDLOT CATTLE
5.1 Abstract

A large proportion of newly arrived feedlot cattle are affected with severe bovine respiratory disease (BRD) during the feeding period; therefore, economic losses could be reduced by accurate and early detection of BRD. Challenges associated with visual BRD detection have led to development of new methods to improve accuracy, timing and predictability. The objective of the current review was to provide a summary of confirmatory tests, early detection methods and methods to predict unfavourable (multiple treatments) or fatal BRD outcomes. A descriptive rapid systematic review was performed in Promed and CAB Abstracts, including 28 peer-reviewed publications. Although widely used, haematology using white blood cell counts and differential blood profile had low sensitivity when used in a serial evaluation following visual detection. However, scientific evidence promotes the use of haptoglobin, a positive acute phase protein, to confirm BRD status. Pathogen identification and immune response provided further evidence for a lack of accuracy of visual BRD detection. Automated monitoring systems have been successfully implemented in both experimental infection and naturally occurring BRD. Specifically, the use of feeding behaviour, infrared thermography and reticulo-rumen boluses had promising results in detecting BRD cases days prior to visual identification. Blood haptoglobin concentrations at the time of first visual detection predicted multiple treatments but not mortality. Retrospective analysis of routinely collected treatment data can be used for automated classification methods to identify cattle at risk for an unfavourable BRD outcome. Several methods (i.e. breath analysis, ultrasound, proteomic, elemental and metabolomic data) have been reviewed that need
further study before their efficacy can be appropriately evaluated. Similarly, natural infection studies are needed to evaluate sensitivity and specificity of location monitoring systems, accelerometers and pedometers for use in early BRD detection.

5.2 Introduction

Despite control efforts, bovine respiratory disease (BRD) remains the most common and economically important disease in the modern feedlot industry. Approximately 21 and 9% of cattle arriving with a bodyweight of < 318 kg and ≥ 318 kg respectively, are affected by BRD during the feeding phase (USDA, 2013a). The detrimental economic effects of BRD increase as severity and number of treatments increase (Gardner et al., 1999; Jim, 2009; Schneider et al., 2009; Cernicchiaro et al., 2013).

Traditionally, feedlot personnel evaluate cattle health subjectively based on cattle behaviour and appearance (i.e. visual appraisal), which have limited sensitivity and specificity (62 and 63%, respectively) for detecting BRD (White and Renter, 2009). Indeed, as prey animals, cattle mask signs of weakness and disease which make them difficult to detect, especially early in the disease progress (Weary et al., 2009). Furthermore, the clinical signs expressed by sick animals are usually not specific to BRD (i.e. depression, loss of appetite, respiratory character change and increased rectal temperature; DART) (Griffin et al., 2010). Although widely used, treatment records using DART signs are poorly correlated with BRD mortality (Griffin, 2014).
The most expensive group of feedlot cattle is the one requiring multiple treatments or that die during the feeding period. Besides treatment costs, cattle treated multiple times are commonly less productive during the feeding period (Cernicchiaro et al., 2013). Costs of mortality include the purchase price, feed, processing, medical, disposal and labour costs and interest on invested money (Loneragan et al., 2001). Key to effective treatment of respiratory disease with low relapse rates and lower mortality is early intervention (Janzen et al., 1984; Ferran et al., 2011). However, clinical signs of BRD appear late in the disease process (Timsit et al., 2011a).

Thus, new methods have been developed to focus on accurate and early detection of BRD. The objectives of the current rapid systematic review (Young et al., 2014) were to provide a comprehensive summary of methods and technologies currently in use to improve BRD diagnostics, timely BRD detection ante-mortem and describe prognostic methods to identify cattle with unfavourable BRD outcome at the time of first treatment.

5.3 Methods

5.3.1 Definitions for the search

The review comprised confirmation, early disease detection, and prognosis of BRD. The definitions are as follows:

1) The case definition of BRD in the included manuscripts has to be based on a minimum of clinical signs of respiratory disease and elevated rectal temperature (threshold varied among studies, but > 39.5° C).
2) Early disease detection methods are methods used to detect sick cattle before signs of BRD detectable by visual appraisal appear.

3) Confirmatory tests are laboratory and other tests that are used to increase specificity of the BRD case definition.

4) Prognostic methods identify cattle at risk for multiple treatments or fatal outcome.

5.3.2 Criteria for considering studies

The review question was defined based on key concepts in terms of population (P), intervention (I), comparator (C), outcome (O) and study design (S) as described in the PRISMA statement (Moher et al., 2009). The population of interest for this review was newly received feedlot calves. Studies were considered if they included beef breeds at the age of weaning (6-9 mo) up to backgrounders (11-12 mo) (Deblitz and Dhuyvetter, 2013). The study was not looking for interventions but rather methods and technologies to detect and diagnose bovine respiratory disease and provide a prognostic outcome. The comparator was the current industry standard. Studies were included if they used visual detection methods and at least hyperthermia (> 39.5°C). Outcomes of interest were confirmatory, early detection, or prognostic means to evaluate the efficacy of the detection method. Studies reporting outcomes on a cohort level (outcome by lot or pen) were excluded. All study designs were considered for this review.
5.3.3 Search strategy

Due to the scope of the study (rapid systematic review), only studies in English language published in international peer-reviewed journals were considered. Studies of all available years were identified by electronic searches in CAB (Commonwealth Agricultural Bureau) Abstracts and PubMed. The search strategy included the population, detection method, comparator and outcome (Table 5.1). A search combining individual terms with “AND” was used to identify relevant articles. Searches were performed in December 2014 and January 2015 with the last update on February 17, 2015.

5.3.4 Selection of studies

One reviewer (BW) assessed titles and abstracts for eligibility. If the article appeared relevant, the same reviewer evaluated the full text of the manuscript for inclusion. Data from all relevant manuscripts were extracted. Relevant studies described diagnostic, early detection or prognostic methods to detect naturally occurring or experimentally induced BRD. Only original studies were included. Data from several trials reported in one manuscript were extracted separately. The data extraction process was verified by a second reviewer (KO). The following data were extracted: method or technology evaluated, study population (n), BRD cases, early detection, confirmation, and prognostic outcome. With the large variability in methods, study designs and reported outcomes, we decided to report outcomes as a descriptive review.

Study outcomes were stratified into confirmatory, early detection and prognostic outcomes. Additionally, experimental infection studies were graphically presented.
5.4 Results and Discussion

Following evaluation of titles, abstracts and complete review of the manuscript, 28 articles were included in this review (Figure 5.1), including 3 retrospective data analyses (Amrine et al., 2014; Noffsinger et al., 2014; Theurer et al., 2014), 7 case controls (Allen et al., 1991; Allen et al., 1992; Quimby et al., 2001; Abutarbush et al., 2012; Burgess et al., 2013; Idoate et al., 2014; Rademacher et al., 2014), 1 cohort study (Purdy et al., 2000), 11 longitudinal studies (Sowell et al., 1999; Buhman et al., 2000; Berry et al., 2004; Schaefer et al., 2007; Burciaga-Robles et al., 2009; Timsit et al., 2011a; Timsit et al., 2011b; Schaefer et al., 2012; Buczinski et al., 2014; Taylor et al., 2014; Wolfger et al., 2015b), 5 infection trials (Aich et al., 2009; Burciaga-Robles et al., 2010; Hanzlicek et al., 2010; Rose-Dye et al., 2011; Theurer et al., 2013b), and 1 combined longitudinal and infection trial (McCorkell et al., 2014).

5.4.1 Excluded studies

Out of the 70 studies included in full-text screening, 1 was excluded due to cohort-level outcomes, 2 described technique development, 22 presented an outcome that was neither diagnostic confirmation, early detection related nor prognosis, 11 reported single pathogens, 2 were review papers, 2 with had no full-text available and 2 described only chronic pneumonia.

5.4.2 Part 1: Confirmatory diagnostics
5.4.2.1 White blood cell count

White blood cell count, specifically neutrophilia, left shift, neutropenia, lymphopenia, or increased neutrophil/lymphocyte ratio, has been used for decades to confirm mild to severe inflammation in cattle (Jones and Allison, 2007). Based on an infection trial, exposure to persistently infected (PI) steers with bovine viral diarrhea virus (BVDV) resulted in significantly less white blood cells (WBC) and neutrophils, whereas inoculation with *Mannheimia haemolytica* resulted in greater WBC and neutrophils. Lymphocyte count decreased with exposure to PI animals and *M. haemolytica* (Burciaga-Robles et al., 2010). After infection with *M. haemolytica* WBC and segmented neutrophils increased on d 1, but decreased to baseline thereafter (Hanzlicek et al., 2010). Sensitivities and specificities of WBC in naturally occurring acute BRD cases ranged from 25 to 78% and from 80 to 94%, respectively (Schaefer et al., 2007; Schaefer et al., 2012). In a longitudinal study 52% of naturally occurring BRD cases had increased or decreased WBC and neutrophil counts, and 20% had an increase or decrease in lymphocyte counts (Wolfger et al., 2015b). Given the wide range and often low accuracy, WBC, neutrophils, lymphocytes and their respective ratios are of limited value for confirming BRD in feedlot cattle.

5.4.2.2 Acute Phase Proteins

Positive acute phase proteins [i.e. haptoglobin (HP), serum amyloid A (SAA), fibrinogen (FB), apolipoprotein AI and lipopolysaccharide binding protein (LBP)] are expected to increase in cattle with inflammation and tissue damage, whereas negative acute phase proteins (i.e. transferrin) should decrease (Jones and Allison, 2007).
Changes in acute phase proteins have been associated with BRD in infection trials (Aich et al., 2009; Burciaga-Robles et al., 2010; Theurer et al., 2013b) and naturally occurring BRD (Idoate et al., 2014; Wolfger et al., 2015b) (Table 5.2). On d 0.5, 1, 2, 3 and 7 after *M. haemolytica* infection (pi) HP was elevated in infected versus control cattle, with no difference reported on d 9 pi (Theurer et al., 2013b). In an infection trial with BHV-1 and *M. haemolytica*, HP and apolipoprotein AI were significantly elevated by d 4 after viral exposure and prior to *M. haemolytica* infection (Aich et al., 2009). Comparable results were reported in naturally occurring BRD outbreaks (Idoate et al., 2014; Wolfger et al., 2015b). On the day of primary BRD diagnosis, compared to clinical illness, both serum HP (cut-off ≥ 0.81 mg/mL) and LBP (≥ 0.33 µg/mL) levels were 93% sensitive, whereas HP levels were 86% and LBP 93% specific. Furthermore, 94% of clinically sick cattle were had serum HP levels that were higher than 0.15 mg/mL, 76% had SAA levels that were higher than the cut-off and 30% had fibrinogen levels that were above the cut-off (Wolfger et al., 2015b). In contrast, transferrin was not significantly higher in BRD cases compared to time-matched controls (Idoate et al., 2014). Therefore, HP and potentially LBP can be used for laboratory confirmation of BRD, whereas limited evidence for other acute phase proteins currently hampers conclusion.

5.4.2.3 Detection of BRD pathogens

Establishing the presence of causative pathogens might aid in confirming BRD status, choice of treatment and prophylaxis (e.g. targeted vaccination strategies). However, differentiation of BRD affected cattle based on visual signs and hyperthermia (≥ 40° C) from controls based on the respiratory flora was deemed difficult (Allen et al.,
1991). Isolation of \textit{P. multocida} was more frequent in cases than controls in both nasal swabs and bronchoalveolar lavage (BAL), and isolation of \textit{M. haemolytica} was more frequent in cases using nasal swabs. However, frequency of isolation of all other tested bacteria (\textit{M. bovis}, \textit{M. bovirhinitis} and \textit{H. somnus}) from the upper and lower respiratory tract was similar in cases versus controls. A more recent study provided further evidence for more frequent detection of \textit{M. haemolytica} in nasal swabs of cases (45%) compared to controls (28%), whereas \textit{P. multocida} was negatively associated with BRD (P < 0.02) (Taylor et al., 2014). Therefore, clear differentiation between cases and controls on the basis of respiratory flora therefore seemed challenging.

5.4.2.4 Stress-related hormones

Cytokines stimulate the hypothalamic-pituitary-adrenal axis and increase peripheral levels of glucocorticoid concentrations (Salak-Johnson and McGlone, 2007). Substance P regulates nociceptive neurons and can be involved in pain, stress and anxiety (DeVane, 2001).

Blood cortisol concentrations have been measured in cattle to confirm BRD (Schaefer et al., 2007; Schaefer et al., 2012; Theurer et al., 2013a). Infected heifers had significantly higher concentrations of both cortisol and substance P concentrations immediately after \textit{M. haemolytica} infection (0.5 to 1 d pi), but were not significantly different d 2-7, whereas substance P decreased on d 7 compared to uninfected control heifers (Theurer et al., 2013b). In a natural BRD infection, serum cortisol (> 105.9 µmol/L) at the time of BRD diagnosis had a diagnostic sensitivity of 100%, but a specificity of only 54% (Schaefer et al., 2012), whereas salivary cortisol had a sensitivity
of 70% and specificity of 53% in an earlier study by the same research group (Schaefer et al., 2007). Elevated concentrations of cortisol and substance P are not specific to BRD infection or inflammation and cortisol is elevated in common stress situations (Grandin, 1997).

5.4.2.5 Direct measurement of pulmonary changes

In addition to blood and serum analysis, other analytical methods examining pulmonary changes have been proposed for BRD confirmation, but all appear of limited value (Allen et al., 1991; Burciaga-Robles et al., 2009; Burgess et al., 2013). Percutaneous lung biopsy was deemed easy to perform, but histopathological changes were only observed in 9.5% of all successfully extracted samples of BRD cases (Burgess et al., 2013). Samples obtained by BAL showed inflammatory changes in the lower respiratory tract of cases (solely based on clinical signs) and controls. However, an increased proportion of neutrophils in BAL fluid increased the probability of isolating \(P.\ multocida\) and \(M.\ haemolytica\) (Allen et al., 1992). Breath analysis of exhaled (e) CO, CO\(_2\) and N\(_2\)O and their respective ratios at the time of treatment revealed that eN\(_2\)O:eCO\(_2\) and eCO:eCO\(_2\) increased with number of treatments (Burciaga-Robles et al., 2009). However, breath analysis in cattle is still in an experimental stage and further evaluation appears necessary before it can be recommended for BRD confirmation. Furthermore, the use of BAL to evaluate pulmonary health further indicated the poor accuracy of clinical signs for the diagnosis of BRD.

Thoracic ultrasonography has recently been explored for BRD confirmation (Abutarbush et al., 2012; Buczinski et al., 2014). Ultrasonography identified lung lesions
in 29% of BRD cases, 10% of arrival fever cases and 16% of controls (Abutarbush et al., 2012). In contrast, a similar study (Rademacher et al., 2014) evaluating 29 BRD cases and 15 controls, reported significantly more sites with consolidation, pleural irregularities, maximal depth of consolidation, maximal area of consolidation, total consolidated area and affected sites in BRD cases than controls ($P < 0.001$). Based on contrasting results and limited sample sizes we inferred that more studies are needed to evaluate the value of ultrasonography to confirm BRD.

5.4.3 Part 2: Early disease detection

The late appearance of clinical signs of BRD hampers early and efficient treatment of BRD cases. However, automated recording systems monitor cattle without human presence; therefore, this approach may increase the probability of identifying mild or early stages of disease (Weary et al., 2009).

5.4.3.1 Automated behaviour monitoring

Evidence for differences in behaviour between sick and healthy cattle

Sick animals commonly decrease feeding and increase time of rest as a means to coordinate energy expenditure (Hart, 1988). Output from location monitoring (Ubisense Series 7000 Compact Tag; Ubisense, Denver, CO) and accelerometers (GP1 SNSR; Reference LLC, Elkader, IA) provided evidence for differences in behaviour between $M. \text{haemolytica}$-infected heifers with mild symptoms of BRD and control heifers (Figure 5.2). However, there was no significant treatment effect on pedometer output (NL-800;
New-Lifestyles Inc., Lees Summit, MO) (Theurer et al., 2013b). In another *M. haemolytica* infection study using accelerometers, there were lower step counts (*P* < 0.05) and decreased standing time after inoculation compared to measurements taken prior to infection (Hanzlicek et al., 2010).

More evidence was provided in natural BRD outbreaks where individual feeding behaviour (Growsafe, Airdrie, AB, Canada) was monitored (Sowell et al., 1999; Buhman et al., 2000; Quimby et al., 2001; Wolfger et al., 2015b). Shorter daily time at the feedbunk and less frequent visits were recorded for cattle with BRD compared to those that were visually healthy 1 to 4 days on feed (DOF) and 11 to 27 DOF (Sowell et al., 1999; Buhman et al., 2000).

*Application for early BRD detection*

Knowledge regarding different feeding patterns in healthy and sick cattle was used to identify BRD-affected cattle earlier than visual appraisal (Quimby et al., 2001; Wolfger et al., 2015b). Using a cumulative sum chart of automatically collected feeding time, 85 and 96% of cattle with visual BRD signs were predicted on average 4.5 d prior to visual detection (Quimby et al., 2001). Further development of the same technology allows for intake measuring during bunk visits. In a predictive algorithm, mean intake per meal, daily frequency of meals, and interval between meals identified BRD-affected cattle up to 7 d prior to visual identification. Furthermore, 60 to 81% of BRD cases were classified as sick, whereas 77 to 85% of visually healthy cattle were correctly classified between 1 and 7 d prior to visual identification (Wolfger et al., 2015b). Therefore, feeding behaviour can be used to identify cattle prior to visual detection.
5.4.3.2 Automated temperature measurements

*Evidence for differences in temperature between sick and healthy cattle*

Based on expected changes in body temperature, several automated temperature measure devices have been applied for BRD detection: reticulo-rumen boluses (Rose-Dye et al., 2011; Timsit et al., 2011a; Timsit et al., 2011b), infrared-thermography (IRT) measuring radiated orbital (Schaefer et al., 2007; Schaefer et al., 2012) or nasal passage and nasal planum surface temperature (Theurer et al., 2013b) and temperature-sensing ear-tags measuring tympanic temperature (McCorkell et al., 2014).

Two *M. haemolytica* infection trials reported altered body and surface temperatures after infection (Rose-Dye et al., 2011; Theurer et al., 2013b). Average daily ruminal temperature (SmartStock LLC, Pawnee, OK) was only elevated on the day of *M. haemolytica* challenge. However, in the group of cattle housed with BVDV PI-steers, hourly ruminal temperature was intermittently elevated prior to and post-*M. haemolytica* infection (Figure 5.2) (Rose-Dye et al., 2011). Nasal planum surface temperature measured by IRT (ThermaCAM S65, FLIR Systems, Wilsonville, OR) was higher in *M. haemolytica* infected heifers 8 and 48 h pi and nasal passage temperature (Biothermal RFID Chip, Destron Technologies, Round Rock, TX) was lower between 14 and 18 h pi.

In naturally occurring BRD maximum orbital temperature measured with IRT (FLIR Comp., Boston, MA), had a positive predictive value of 86% and a negative predictive value of 100% on the day of visual BRD identification (Schaefer et al., 2012). In an earlier study, the same research team reported 87% positive predictive value, and 67% negative predictive value on the day of visual BRD detection (Schaefer et al., 2007).
The percentage of BRD-affected calves exceeding 39.8°C tympanic temperature (Fever Tags®, Amarillo, TX, USA) varied between 15-85% in a study that used several groups of newly-arrived feedlot cattle (McCorkell et al., 2014). Therefore, changes in body temperature can be reliably measured with IRT and reticulo-rumen boluses, whereas technology measuring tympanic temperature might need further development.

**Application in early BRD detection**

Hyperthemia is one of the first signs of BRD, based on infection trials (Rose-Dye et al., 2011; Theurer et al., 2013b). From 4-6 d prior to visual detection of naturally occurring BRD, maximum orbital temperature was 54% sensitive and 68% specific. The ratio between individual mean temperature and the group orbital temperature increased sensitivity to 69% and specificity to 77% (Schaefer et al., 2007). In another trial, 73% of steers with reticulo-rumen hyperthemia (> 39.7°C) lasting > 6 h (Thermobolus, Medria SAS, Chateaugiron, France) in a naturally occurring BRD outbreak were subsequently confirmed as BRD cases (based on rectal temperature > 39.7°C and abnormal pulmonary sounds). The study additionally provided evidence that first clinical signs detectable by visual appraisal appear between 12 and 136 h after hyperthermia (Timsit et al., 2011a). Therefore, hyperthermia can provide first evidence of BRD in feedlot cattle, but further clinical evaluation of suspect animals is necessary to confirm BRD.
5.4.4 Part 3: Prognostic tests

Chute-side tests at the time of treatment could help identify cattle at higher risk for unfavourable BRD outcome (i.e. multiple treatments or death) and enable feedlot managers to more effectively manage those cattle.

5.4.4.1 Infection markers

Proteomic, metabolite and serum elemental profiles (i.e. minerals, trace elements) can be used to predict mortality. Elemental profiles (i.e. Li, B, Mg, P, Ca, Ti, Cr, Fe, Cu, Zn, Se, Sr, Mo, Cd, and Ba), lower lactate and higher cortisol concentrations predicted mortality prior to viral infection. In contrast, higher glucose concentrations 4 d after viral infection were associated with survival (Aich et al., 2009).

Although, lactate concentrations could not predict fatal disease outcome at the time of BRD diagnosis in naturally occurring BRD, a 1-log increase in follow-up lactate concentrations, (3, 6, 9 and 15 d after first treatment) increased the hazard of dying prior to the next observation by a factor of 36.5 (95% CI: 3.5-381.6) (Buczinski et al., 2014).

Further studies are needed to assess the true prognostic nature of lactate.

5.4.4.2 Direct indicators for lung lesions

Several methods have been used recently to identify lung lesions directly in BRD cases at the time of first identification. The methods described below were only described in single published papers.
A stethoscope that automatically assigns respiratory scores from 1 to 5 at first BRD identification (Whisper® Veterinary Stethoscope, Plymouth, MN, USA), predicted survival of BRD cases moderately (AUC = 0.64). Including a cut-off for fever significantly improved predictability (AUC = 0.69) (Noffsinger et al., 2014).

Ultrasonography at the time of first treatment identified significantly more sites with consolidation, pleural irregularities, maximal depth of consolidation, maximal area of consolidation, total consolidated area and affected sites in BRD cattle that died compared to surviving cattle ($P$-value < 0.05) (Rademacher et al., 2014). More studies are necessary to provide adequate evidence for the effectiveness of both methods.

5.4.4.3 Treatment outcome prediction

Feedlots routinely collect valuable treatment and cohort information on individual cattle. Information obtained from various feedlots and several years might be used to predict cattle that will not finish the production cycle (i.e. death, culling, premature harvest). Rectal temperature at first BRD diagnosis, DOF, sex, quarter of the year and body weight on arrival had limited predictive value (AUC = 0.646) to identify cattle that did not finish the production cycle (Theurer et al., 2014). However, another study used retrospective treatment records and arrival time (month, quarter and year) of 23 feedlots collected over 10 y to train, optimize and evaluate nine classifiers that identify cattle not finishing the production cycle (Amrine et al., 2014). Some classification methods had an almost perfect accuracy (95%) on identification of specific sub-groups of cattle, but the dataset (feedlot identity) highly influenced the accuracy to detect cattle not finishing the production cycle, which resulted in limited generalizability (Amrine et al., 2014).
Identification of the correct classification method for individual feedlots should be further explored and could enable targeted management of high-risk cattle at the time of first BRD treatment.

5.5 Implications and Limitations

Results of this rapid systematic review enable researchers, veterinarians and producers to compare various methods and technologies currently available to confirm BRD, detect BRD early and for prognosis of detrimental BRD outcome. Although a meta-analysis could not be performed due to large variability in study designs and outcomes, a comprehensive summary of proposed methods and technologies was provided.

Economic considerations of methods to confirm and early detect BRD or prognostic methods should always precede investment in commercial feedlots. One study suggested early detection methods need to cost < CAD 4.06 per steer to improve economic revenues for commercial feedlots in Canada and the US (Wolfger et al., 2015a). A recent economic analysis additionally reiterated the need for more specific methods, as increasing specificity created more rapid, positive change in net returns compared to increasing sensitivity (Theurer et al., 2015).

By no means can this study claim completeness in all available technology or methodology that could potentially be used for either of the objectives. Instead, this review summarized the technology that has already been applied on feedlot cattle of a certain type (freshly-weaned to yearling) and evaluated for effectiveness in BRD
detection. New technology, however, is evolving quickly and future use for BRD
detection is likely. Examples are feeding behaviour monitoring systems based on
accelerometers (Bikker et al., 2014), feedbunk antennas detecting tags attached to the leg
(Devant et al., 2012) and alternative location monitoring systems.

The major limitation of research evaluating diagnosis of BRD is the lack of a gold
standard. The true gold standard for BRD can, however, only be a pathological post-
mortem evaluation immediately after diagnosis of BRD, which for ethical and economic
reasons, is usually avoided. Therefore, every research group developed their own
definition of a “true” BRD case. The studies evaluated in this review used clinical illness
scoring and rectal temperature cut-offs (between 39.5 and 40.5°C) to verify disease
status.

5.6 Summary

Existing evidence supports the use of HP to confirm BRD status, but there was
limited value for differential white blood cell counts and bacteriology in confirming BRD
cases. Initial studies using breath analysis, ultrasonography and percutaneous lung biopsy
did not provide promising results for BRD confirmation.

Early detection of BRD has been successfully performed using IRT, ruminal
temperature boluses and feeding behaviour-monitoring systems. Although promising in
infection trials, further studies are necessary to evaluate sensitivities and specificities of
location monitoring systems, accelerometers and pedometers for the use of early BRD
detection in naturally occurring BRD.
Table 5.1: Search terms to extract manuscripts of interest. Rows were combined with AND

<table>
<thead>
<tr>
<th>Feedlot* OR concentrated animal feeding operation OR CAFO* OR feeding unit OR finishing unit OR feed yard OR feedyard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle OR calves OR bovine</td>
</tr>
<tr>
<td>Respirator* OR BRD* OR bovine respiratory disease OR shipping fever OR bronchopneumonia OR undifferentiated fever</td>
</tr>
<tr>
<td>Detect* OR diagnos* OR radio-frequency identification system OR RFID OR thermography OR reticulo-rumen temperature OR ruminal OR infection marker OR acute phase protein OR temperature OR accelerometer OR sceen* OR eating behaviour OR behaviour OR behaviour OR eating behaviour OR feeding behaviour</td>
</tr>
</tbody>
</table>

* Wildcard operator (enables retrieval of records with any character after the asterisks.)
Table 5.2: Acute phase protein changes during bovine respiratory disease (BRD) compared to controls (C)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Study design</th>
<th>n</th>
<th>BRD</th>
<th>C</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aich (2009)</td>
<td>Infection trial (BHV-1 + M. haemolytica)</td>
<td>20</td>
<td>6</td>
<td>14</td>
<td>HP - ↑ d4&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Apolipoprotein AI - ↑ d4&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Berry (2004)</td>
<td>Longitudinal</td>
<td>245</td>
<td>64</td>
<td>45</td>
<td>HP - treatment &gt; recovery</td>
</tr>
<tr>
<td>Burciaga-Robles (2009)</td>
<td>Longitudinal</td>
<td>337</td>
<td>222</td>
<td>42</td>
<td>HP highest at initial treatment</td>
</tr>
<tr>
<td>Burciaga-Robles (2010)</td>
<td>Infection trial (BVDV pi + M. haemolytica)</td>
<td>24</td>
<td>18</td>
<td>6</td>
<td>HP - ↑ d0.75-d4</td>
</tr>
<tr>
<td>Idoate (2014)</td>
<td>Prospective case-control</td>
<td>77</td>
<td>14</td>
<td>14</td>
<td>HP treatment (cut-off: 0.81 mg/ml)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sensitivity = 92.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Specificity = 85.7%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LBP treatment (cut-off 0.33 μg/ml)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sensitivity = 92.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Specificity = 92.9%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Transferrin – not significant</td>
</tr>
<tr>
<td>Purdy (2000)</td>
<td>Cohort</td>
<td>101</td>
<td>73</td>
<td>28</td>
<td>HP: diagnosis 2.36x &gt; recovery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fibrinogen – not significant</td>
</tr>
<tr>
<td>Theurer (2013)</td>
<td>Infection trial (M. haemolytica)</td>
<td></td>
<td></td>
<td></td>
<td>HP - ↑ d0.5-d3&lt;sup&gt;1&lt;/sup&gt; &amp; d7&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HP-matrix metalloproteinase-9 ↑ d2-d3&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cases: 75.4% SAA pos.</td>
</tr>
</tbody>
</table>
### Reference

<table>
<thead>
<tr>
<th>Study design</th>
<th>$n$</th>
<th>BRD</th>
<th>C</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cases: 30.4% Fibrinogen pos.</td>
</tr>
</tbody>
</table>

1 day relative to bacterial infection

HP haptoglobin

LBP Lipopolysaccaride binding protein
Figure 5.1: Stepwise exclusion and exclusion of literature evaluated for inclusion in the rapid systematic review (Moher et al., 2009)
Figure 5.2: Clinical and behavioural signs change after viral and bacterial infection; data adapted from (Aich et al, 2009; Hanzlicek et al, 2010; Rose-Dye et al, 2011; Theurer et al., 2013)
6.1 Summary of work presented

The main objective of this thesis was to explore automated recording methods for early BRD detection and the economic need for it. Collectively, the previous 4 chapters presented in this dissertation explore alternative methods of BRD detection in feedlots that can improve timing or accuracy compared to commonly used visual detection methods. Feeding behaviour in terms of feed intake and feeding time was used to predict laboratory confirmed BRD prior to visual detection in chapter 2. Two alternative systems to record feeding behaviour were validated in chapter 3, chapter 4 was an economic evaluation of automated feeding behaviour recording systems for their use in early disease detection, and chapter 5 discusses methods to improve detection accuracy, timing of BRD detection and prognosis of BRD outcome in feedlots.

In chapter two, feeding behaviour was recorded for 213 newly arrived high-risk feedlot steers. An electronic monitoring system (Growsafe Ltd, Airdrie, AB, Canada) scanned the RFID tag at 1-s intervals while steers were at the feedbunk and calculated feed disappearance with an integrated scale. Daily summarized feed intake and feeding time variables (i.e. mean, sum, minimum, maximum) were used in survival analysis to identify visually sick and laboratory confirmed BRD cases up to 7 days before clinical signs appeared. The best two prediction models included (1) mean intake per meal in combination with meal frequency and mean time between meals, and (2) time at the feedbunk, meal frequency and mean time between meals. Similar to the results of this study, a previous trial predicted BRD in feedlot cattle on average 4.5 days before feedlot
personnel identified disease using feeding time by means of cumulative sums (Quimby et al., 2001). However, our study was the first study including intake variables in a prediction model for BRD in feedlot cattle. Although previous research provided evidence for shorter feeding time in sick cattle, (Sowell et al., 1999; Buhman et al., 2000) the associated intake had previously not been described. Even if not used in disease detection in feedlot cattle, comparable results were reported in disease detection in dairy cows. Cows with severe metritis post-partum consumed less food than healthy cows and spent less time at the feed bunk before calving (Huzzey et al., 2007). Feeding behaviour monitoring, therefore, is a valuable tool that identifies sick cattle before clinical signs of sickness even appear.

New technologies that record feeding time based on various monitoring principles have been developed during the past decades. In chapter three, accuracy of two different methods was evaluated to record feeding time and rumination, and feeding time and activity (i.e. lying, standing, walking) in beef cattle, respectively. The first technology was based on ear-motion detection specific to feeding and ruminating. Feeding was recorded with a high sensitivity of 95% but a specificity of 76%, while rumination was recorded with low sensitivity of 49% and a specificity of 96% relative to live observations. Respective concordance correlations were 0.79 and 0.44 for feeding and rumination. The same technology was previously validated for the use in lactating dairy cows (Bikker et al., 2014). Concordance correlation between visual observations and the ear motion detector was similar in both studies for feeding behaviour, but rumination monitoring had a low concordance correlation in beef cattle (chapter 3), whereas in dairy cows rumination was monitored with high accuracy (CCC = 0.93) (Bikker et al., 2014).
is noteworthy that the cattle used in the two studies differed in breed, sex and age and were fed different diets, which could have accounted for the large differences in rumination monitoring. Additionally, variability between cattle participating in the study was high. One individual had very low concordance correlations of 0.09, which was contrary to other individuals with concordance correlations of 0.98. No explanation for this large variability could be established, but similarly high variability has been reported in young dairy cattle previously (Burfeind et al., 2011). Likely, the large variability can be attributed to different ear-motion during rumination in individuals.

The second validated technology was a leg-attached accelerometer that passively received magnetic waves when in proximity to the feedbunk. Feeding time, lying time and number of steps were recorded and validated against live observations, a previously validated accelerometer, and video observations respectively. Although, both feeding time and lying time were accurately measured by the accelerometer (CCC = 0.98), records of lying frequency and step counting were only moderately accurate with large variability [CCC 0.71 (95% CI: 0.63-0.77) and 0.75 (0.49-0.88)]. The 6-min sampling interval of the accelerometer appeared sufficient for lying time measurements but insufficient for lying bouts. In line with the results presented, a previous publication described that sampling intervals > 2 min were inadequate to accurately predict the number of lying bouts (Mattachini et al., 2013). Step counting accuracy by the tested accelerometer was only moderate, but higher compared to previously validated accelerometers (Mattachini et al., 2013). The accelerometer therefore can be used for accurate measurements of feeding time and frequency of feedbunk visits and lying time.
Lying bouts and step counts estimated using this technology require cautious interpretation.

The three systems used in chapters 2 and 3 all measure feeding time, but only the individual feedbunk system used in chapter 2 was able to record feed intake. In addition to disease detection, feed intake can be used by feedlots to assess feed efficacy of cattle (Schwartzkopf-Genswein et al., 2002; Basarab et al., 2003). For early BRD detection, daily summarized feeding time (mean meal time, meal frequency and mean time between meals), however deemed sufficient (chapter 2). An advantage of both systems in chapter 3 was the ability to monitor other behaviour (rumination and lying time respectively), which could be explored for early BRD detection. The easy installation of both systems and unrestricted feedbunk access compared to the system used in chapter 2 pose additional advantages.

An economic evaluation on the individual feedbunk technology (used in chapter 2) to detect BRD affected cattle was performed in chapter 4. In a thorough economic analysis including published estimates for treatment rate, costs and revenues of cattle and benefits of early BRD detection, the investment costs of $13.7 per animal did not outweigh the benefits of earlier detection. If the RFID technology was used in a typical high-risk period for BRD (20% treatment rate), net-benefits (slaughter price – all expenses) were lower by $9.6 per steer compared to using visual observations. The price of the technology and the true BRD incidence were highly influential for the outcome of the study. A decrease to < $4 per steer or an increase in true BRD incidence to > 47% resulted in higher net-benefits per steer when early disease detection technology was used. The economic study did not account for any other uses of the individual feedbunk
technology, which could reduce the costs of the system per steer and make it more cost-effective for commercial feedlot application.

In chapter 5, the general discussion, current methods to improve detection accuracy, timing and prognosis of detection of BRD in feedlots are summarized by means of a rapid systematic review. Contrary to common practice, haematology using white blood cell count and differential blood profile was not sensitive to confirm BRD status of visually sick cattle. Acute phase proteins, specifically haptoglobin can be used to confirm disease status. Feeding behaviour monitoring systems, infrared-thermography and reticulo-rumen boluses were promising tools to identify BRD-affected cattle prior to visual detection.

6.2 Limitations of the studies presented

Although important for external validity, work with commercial farms often encounters situations where for labour reasons study design has to be compromised. In the study described in chapter 2, clinically healthy cattle were not examined further to confirm health status. The potentially resulting differential misclassification bias likely led to an underestimation of the difference between feeding behaviour in sick and healthy cattle.

Feeding behaviour monitoring with individual feedbunks (chapter 2) restricts cattle to a limited number of feedbunks and does not allow simultaneous feeding of all cattle. This could have affected group-specific feeding behaviour in sick cattle that might
not be as competitive as healthy cattle. Future research should evaluate this effect by using systems that can be installed on commonly used feedbunks in commercial feedlots.

In chapter 3 two technologies were validated, partly based on comparison to visual observations. Inter-observer correlation between the 2 evaluators was tested several times in both trials. Although high inter-observer correlation was achieved, if human observations are used for validation purposes, there is still potential for missed behaviour due to fatigue or distractions. We tried to solve this issue by limiting the time of observations per observation period and day, and the use of an already validated system to evaluate accuracy of the new system. The implication of missed behaviour recordings by the comparator on the results of both studies is therefore thought to be limited.

Simulation studies, such as the economic evaluation in chapter 4, are highly influenced by the quality of data input and are always only a simplified version of complex real-life situations. The uncertainty around parameters can be substantial. For example, only limited data were available on efficacy of early treatment (i.e. reduced relapse rate and mortality) or the likely positive downstream effects early treatment would have on feedlot and slaughter performance. The true value of early disease detection therefore might have been underestimated in the economic evaluation.

6.3 Implications of using early detection methods in feedlots

Clinical signs of BRD show up late in the disease progress (Timsit et al., 2011a), which hampers early treatment. Automated feeding behaviour recording can be used to
identify BRD-affected cattle days before clinical signs appear (chapter 2). Furthermore, if antimicrobial metaphylactic treatment will be reduced in the near future due to fear of antimicrobial resistance, BRD incidence will likely increase and make early BRD detection methods also more desirable from an economic point of view (chapter 4).

6.4 Implication of validation studies

A multitude of technologies have been validated for their use in dairy cattle, but only a few studies provide accuracy estimates for technology monitoring beef cattle. Two methods have been validated in chapter 3 for feeding time recording. With previously mentioned limitations of individual feedbunks, both technologies had high accuracies for feeding time recording and could be used in future research to identify sick feedlot cattle earlier.

6.5 Future directions

This thesis filled several important knowledge gaps, identifying methods to predict BRD-affected cattle. However, several questions should be addressed in future research.

The potential effect of individual feeding units on feeding behaviour of cattle was pointed out in the limitations section in chapter 2. Additionally, high investment costs of individual feedbunks currently do not warrant the implication of this technology for early BRD detection solely (chapter 4). Other feeding behaviour recording systems (e.g. such as those presented in chapter 3) should therefore be used in future research that allows
cattle to feed simultaneously. Comparison to feeding behaviour recorded by the individual feedbunk units would be desirable to evaluate the effect of restricted feedbunk space.

Chapter 2 provided evidence that feeding behaviour recordings are useful to detect BRD in feedlots. However, feeding behaviour changes are not specific to BRD but rather could be used to detect other diseases in feedlots. High incidence of subclinical ruminal acidosis during the late finishing period has been presented in a recent study (Castillo-Lopez et al., 2014), and digestive disorders are the second most common cause of death (Loneragan et al., 2001). Longitudinal studies should be conducted to explore the potential of detection of subclinical and clinical metabolic, production limiting disease.

New methodologies recording not only feeding behaviour but also rumination or activity were validated in chapter 3. In experimental infection trials lying time as well as step counts were different in infected compared to non-infected cattle (Hanzlicek et al., 2010; Theurer et al., 2013b). Longitudinal studies combining multiple behaviour recordings should be conducted, which could increase accuracy of BRD detection if records are used in parallel (behaviour changes in one single behaviour trait indicates disease) or as serial evaluations (establish the first sign of disease and confirm with second etc.).

As pointed out in the limitations of chapter 4, a lack of high quality data on the effect of early BRD detection should encourage future research to conduct double blinded trials evaluating the effect of early treatment on relapse rates, mortality and performance.
REFERENCES


Cernicchiaro, N., B. J. White, D. G. Renter, A. H. Babcock, L. Kelly, and R. Slattery. 2012b. Associations between the distance traveled from sale barns to commercial


Deblitz, C., and K. Dhuyvetter. 2013. Cost of production and competitiveness of beef production in Canada, the US and the EU.


outbreak of respiratory disease caused by bovine respiratory syncytial virus.


Silasi, R. 2007. Early detection of morbidity in feedlot cattle using pattern recognition techniques, University of Saskatchewan, Saskatoon.


USDA. 2013c. Types and Costs of Respiratory Disease Treatments in U.S. Feedlots.


APPENDIX A: COPYRIGHT PERMISSION LETTER

Copyright consent

I, ____________________________, consent to the inclusion of the following manuscripts that I have co-authored in the PhD thesis of Barbara Wolfger for publication with Library and Archives Canada, including the agreements included in the Theses Non-Exclusive License that authorizes Library and Archives Canada to reproduce, communicate to the public on the Internet, loan, distribute or sell copies of the thesis, among other things.


Sincerely,

_________________________   _______________________
Print Name          Date/Signature