THESIS

# ACCOUNTING FOR PRODUCTIVE TIME LOST IN DAIRY CATTLE: DISEASE ADJUSTED LACTATION


Submitted by

Ashleigh Ann McNeil

Department of Clinical Sciences


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Master's Committee:

Advisor: Craig S. McConnel

Franklyn B. Garry
Joleen C. Hadrich
Jason E. Lombard

ABSTRACT

ACCOUNTING FOR PRODUCTIVE TIME LOST IN DAIRY CATTLE: DISEASE ADJUSTED LACTATION

Dairy cow mortality, morbidity, and poor welfare have been of increased concern over the past several decades. Traditionally, dairy farm management has focused on singular costs associated with pathologies without thoroughly quantifying losses tied to disease and consequent death or culling. Within human epidemiology, the economic burden of time lost due to ill-health or early death is measured through the World Health Organization's disability adjusted life years (DALY).

This project utilized the DALY concept to estimate time lost during a lactation due to disease and subsequent early removal of dairy cows. This was accomplished through the development of the disease adjusted lactation (DALact) metric. The DALact is calculated by combining days lost due to illness or injury (DLI) and days lost due to early death or removal (DLRD). The DLI reflects the number of cases during a certain period, multiplied by a disability weight and specific disease duration. The DLRD is comprised of two components: days lost due to death, and days lost due to culling from a given disease. Disability weights for 13 common dairy cow diseases were derived from an international expert opinion survey of dairy producers, managers and veterinarians. The selected disease states included: calving trauma, diarrhea, ketosis, lameness, left displaced abomasum, mastitis, metritis, milk fever, musculoskeletal injury, pneumonia, right displaced abomasum, and retained placenta. Survey participants were asked to estimate the impact of each disease on overall health and milk production. Diseases were classified from 0 (no adverse effects) to 10 (terminal). Validity and scope of participants'

responses were assessed using a modified beta-Pert distribution and median points were used to provide disability weights for the DALact calculation.

To support development of the DALact, collection of disease and removal data from three Kansas dairy farms representing 9,000 Holstein cows began January 1, 2014 and ended on May 26, 2015. A total of 7,233 cows were enrolled in the study across the three dairies. DALact measures were calculated using disease, culling and death data for each disease state while combining the disability weights, duration, and average days in milk at time of removal. Mastitis accounted for the largest category on all three dairies representing 29,779, 23,917, and 36,183 days lost for Dairies 1, 2, and 3, respectively. Conversely, prevalence of mastitis was largest on only Dairy 1 (33%). Lameness was the second largest DALact category for Dairies 2 (9,934) and 3 (29,912) but not for Dairy 1 (pneumonia, 13,571). Prevalence for lameness was largest (35%) for Dairies 2 and 3. The DALact method confirmed that mastitis and lameness are areas of focus, but also highlighted that pneumonia is a primary concern on Dairy 1.

The DALact aims to provide an assessment of the complete impact of mortality and morbidity on time lost in dairy cattle. The end result will be to validate the effectiveness of dairy health oversight and to determine where to focus management to reduce the number and economic impact of preventable removals and diseases while increasing animal welfare.

TABLE OF CONTENTS

# CHAPTER 1: INTRODUCTION

## *1.1 Background*

Historically, agriculture has been an evolving practice. In particular, dairy farms are changing in the United States on multiple levels. Farms are growing in size, particularly in the Western States. They are shifting from smaller (200 cows or fewer) farms to larger (2,000 or more cows) farms (MacDonald, O'Donoghue et al. 2007). The factors leading to this change in herd size are driven by supply and demand of milk products as well as improved technological efficiencies to manage constrained labor, land and inputs (MacDonald, O'Donoghue et al. 2007; Parker Gaddis, Cole et al. 2016).

Dairy farm management practices vary across the United States. While older recording practices involved paper records, a shift towards more advanced record keeping has formed with larger dairies. Development of software that assists in tracking each cow in the herd has supported dairy farms in making better decisions regarding economics and the animal’s well-being. The use of on farm software has allowed for a more thorough approach to analyzing trends in morbidity (disease) and mortality (death) on dairies. These new software programs have allowed dairy producers to focus on herd health and mitigating or preventing disease before it occurs. This allows producers to more effectively allocate their limited time while enhancing the overall efficiency and profitability of the operation.

The inclination toward increasingly detailed animal health records has been a topic of conversation within the dairy industry and academic researchers for numerous years. Complete dairy cow mortality and morbidity records have historically been lacking (McConnel 2010). There is a need for novel approaches to better capture the impact of disease and death on dairies.

Just as we recognize that dairy records related to mortality can be improved through a simulation of human death certificates (McConnel 2010); we can look toward human medical epidemiology to improve assessments of the impact of dairy health problems and guide the industry to make welfare, health, and economic improvements on farms.

Human medical epidemiologists have developed multiple summaries of population health to assess the burden of disease and mortality across the world (WHO 2002). Health experts have applied epidemiological studies to human health records to better understand where to focus health interventions across the globe. From a societal view, these studies are health-centric as the goal is to live a long, disease-free life. From an economic perspective, the aim of these studies is to aid in implementation of cost-effective disease interventions, assess current policies in place, and provide framework for future discussion (Murray, Lopez et al. 1994). To capture these statistics, public health officials often use mortality data but rarely are morbidity data incorporated (Murray and Acharya 1997).

Estimates of human mortality and morbidity typically have not been used together as a health or economic assessment as morbidity registration tends to be incomplete or absent, especially in developing countries. In contrast, information for mortality is often complete and widely available in registration databases (Stouthard, Essink-Bot et al. 1997). According to Murray, population health measures have historically been comprised only of mortality data (Murray 1994). Stouthard also argues mortality figures are advantageous due to their completeness and registration system and acknowledges the difficulty in classifying morbidity (Stouthard 1997). Morbidity is harder to quantify as records can be incomplete, unreliable, and hard to connect to disease patterns. A population's health assessment should be comprised of both aspects to encompass the complementary nature of death and disease in humans.

Mortality estimates are the main focus for public health measures and intervention. These figures are often the most reliable in completeness and interpretation, as a main cause of death must be listed and autopsies are performed if an apparent cause is unknown (Stouthard, Essink-Bot et al. 1997). Mortality-based measures are final and easy to analyze by a plethora of variables such as disease, age, or sex. Historical numbers and rates are easy to use to evaluate burden of disease and impact of diseases (Thacker, Stroup et al. 2006). According to Thacker et al., the leading cause of death in the United States is due to chronic diseases such as cardiovascular disease, diabetes, cancer and chronic lung disease. Mortality figures are also easily examined in age-specific categories that might aid in impacting public health policies. Leading causes of infant deaths include congenital abnormalities, short gestation, and sudden infant death syndrome (SIDS) whereas young adult deaths are dominated by intentional and unintentional injuries (Thacker, Stroup et al. 2006). When basing public health efforts solely on mortality figures, policies should focus on maternal and early development interventions as well as education and safety for young adults.

While morbidity is more difficult to determine final numbers, it should still be considered in order to provide insight into disease burden leading up to death. Morbidity is often assessed by rates of hospitalization for given diseases and basic records can be relatively easy to attain (Thacker, Stroup et al. 2006). However, the biased nature of records leading to a direct cause that can be categorized coupled with the increase in outpatient treatment for conditions that previously required hospitalization lead to misclassification and misinformed decisions about the burden of diseases (Thacker, Stroup et al. 2006). Figures based on hospital records from the United States indicate the leading causes for hospitalization are heart disease, child birth, psychoses, pneumonia, cancer, and fractures (Thacker, Stroup et al. 2006). Determining the factors contributing to these health issues is an important component to public health policy. Deaths associated with these diseases are also not accounted for in hospitalization entry records and remain a vital component to assessing complete burden of disease and focusing public health efforts.

Concentrating efforts on diseases that reduce economic productivity or cause early death should be of equal weight with mortality when discussing interventions (Murray and Acharya 1997). Economic consequences that are associated with less than optimal health states are an integral part of public health summaries. Poor health can affect a population on a micro-economic level (households and firms) as well as a macroeconomic level (a country's current and future gross domestic product) (WHO 2009). Since the mid-1960s, a cost-of-illness framework has been the methodology to estimate the economic impact of diseases (WHO 2009). These studies focused on the economic burden (i.e. direct and indirect costs) of a disease and aimed to estimate the maximum amount that could be saved or gained by a public health intervention or disease eradication program (Segel 2006). The knowledge gained from these studies coupled with mortality and morbidity studies can provide valuable guidance to policy makers for resource allocation. A 1997 report from the Medical Expenditure Panel Survey (MEPS), which provides national health care spending statistics for the noninstitutionalized U.S. population, found that one-third of direct medical costs in treatment were for heart disease, cancer, and trauma (Thacker, Stroup et al. 2006). Chronic diseases accounted for the remaining two-thirds (Thacker, Stroup et al. 2006). MEPS' report highlighted the need for health guidance in those areas but did not account for the indirect costs related to economic productivity (e.g. time off work, psychological stress). Direct medical costs are relatively easy to estimate and available and when combined with mortality and morbidity data can provide a valuable economic burden of disease summary.

By 1992, the WHO determined there was a need for a Global Burden of Disease (GBD) study to assess mortality and morbidity for further cost effectiveness measurements (Prüss-Üstün, Mathers et al. 2003). The GBD study provided an economic measurement for nations to aim health efforts at what factors were costing and causing the most disability and premature death. The first GBD study was initiated at the request of the World Bank in collaboration with the World Health Organization with three primary goals (Murray and Lopez 1997). The first goal was to provide information on non-fatal health outcomes for discussion at global public policy gatherings; which are typically focused on the mortality component (Murray and Lopez 1997). The second goal was to develop impartial epidemiological assessments for key disorders, and the third goal was to quantify the burden of disease with a summary measure that could also be used in cost-effectiveness analyses (Murray and Lopez 1997). The results of the first study and subsequent reports have described estimates of mortality for 107 causes of death by age, sex, and region as well as developed consistent estimates of incidence, prevalence, duration, and case-fatality for 483 sequelae of the 107 causes (Murray and Lopez 1997).

The measurement to collectively describe the study’s results was the disability adjusted life year metric (DALY), which was specifically developed for the GBD study. DALYs are a composite estimate of time spent in ill-health and premature death, allowing the GBD study to compare non-fatal health outcomes with early deaths (Murray and Lopez 1997). As mentioned previously, public health policy efforts are often discussed as measures of mortality and the need for a global measure of morbidity was apparent to discuss the cost and health lost due to early death or disability (Murray and Acharya 1997). In limited places, there is availability of partial prevalence and/or incidence data; however, the data can be unreliable for public health policy making (Murray 1994).

### *1.2 The DALY and the DALact*

The WHO has developed a measure to assess productivity and welfare lost due to premature death and disease. The metric has similar goals that can be applied to evaluate dairy cow wellness and early death. Similar to human disease traits, dairy cow diseases can reduce milk production, affect welfare issues, and strain farm economics (Dhakal, Tiezzi et al. 2015; Parker Gaddis, Cole et al. 2016). The objective of the research described in the following chapters is to develop a metric similar to the DALY that can be applied on dairy farms to quantify time lost due to death and disease. The disease adjusted lactation yield (DALact) aims to use the same principals behind the DALY to estimate time lost on the farm due to disease and early removal via culling or death. The calculation of the DALact incorporates a set of standard disability weights that were derived from a survey of experts in the industry (Chapter 2). The application of these weights to morbidity and mortality data on farms yields a summary measure that assesses which disease are leading to the most time lost to disease and death on dairy farms (Chapter 3). Once calculated for a dairy, this metric allows the producer to allocate resources to reduce the economic and welfare impact of disease and death on the operation.

### *1.3 Disability weights background*

The DALY measurement is comprised of disability weights, years of life lost due to disability (YLD) and years of life lost due to premature death (YLL) (Murray and Acharya 1997). YLD's and YLL's are components of the DALY that measure morbidity and mortality, respectively. A DALY can be thought of as one year of "healthy" life lost and the subsequent disease burden measurement as the gap between a diseased population and that of a comparative reference population (Prüss-Üstün, Mathers et al. 2003). Essentially, DALYs measure the gap between how a given disease affects a population compared with a situation where everyone lives up to the standard life expectancy and in perfect health.

Along with YLD and YLL measures, another integral component of the DALY are disability weights. A need for a standardized measure of well-being when evaluating the effect of non-fatal health consequences was evident. Initial disability weights were developed in accordance with the DALY during the GBD study in 1992. Specifically, disability weights are an essential component of the disability measure (YLD). When attempting to combine premature death and non-fatal health states into one, developers of the DALY uncovered a rift between conditions that mainly cause morbidity and those that mainly cause mortality (Stouthard, Essink-Bot et al. 1997). Summary measures that include a wide plethora of health characteristics, such as severity and duration, need to have accountability for those differences. An acute condition (such as cholera or pneumonia) would fit nicely into the mortality component-either the patient dies or has recovered in a relatively brief time (Stouthard, Essink-Bot et al. 1997). A chronic condition such as a musculoskeletal injury or dementia causes a relatively long period of non-fatal discomfort but a chronic ill-health state-and would fit well into the morbidity component (Stouthard, Essink-Bot et al. 1997). In general, conditions that have rapid fatality cause little morbidity but high mortality, alternatively, conditions that are chronic have high morbidity but little mortality (Stouthard, Essink-Bot et al. 1997). A health summary that attempts to join mortality and morbidity finds that diseases that primarily cause death will dominate the mortality component and chronic diseases will control the morbidity outcome. Hence, a different health conclusion is discerned depending on whether it is mortality driven or morbidity driven. A common denominator to combine the two measures for comparison is necessary.

Disability weights are derived using a panel of health experts who assess the physical, mental, and social functioning of a human afflicted with a given condition (Stouthard, Essink-Bot et al. 1997). The severity of a disease is measured on a scale of 0.00 (no adverse function) to 1.00 (extreme functional consequences) (Stouthard, Essink-Bot et al. 1997). The level of severity indicates the functional consequences that disease and subsequent stages has on overall welfare of a person. For example, a common head cold has a disability weight of 0.1 and bipolar disorder has a weight of 0.6 (Murray and Acharya 1997). These weights are relative and comparative to other diseases but should strive to be standard and invariant over time (Essink-Bot and Bonsel 2002). Standardization of disability weights and therefore the DALY allows for comparison of time lost (in early death and time spent with a disease). One key issue to address is the difference between acute and chronic stages of diseases and how they can be compared relative to each other. An acute, common cold only lasts a week whereas bipolar disorder affects a patient in varying severities for their entire life. Disability weights, when combined with epidemiological data, account for the fluctuating severities to give a standard assessment that can be used as a comparative measure between and across diseases.

Disability weights are only pertinent if the epidemiological data to combine with them is complete and relevant. Disability weights are not meant to be a standalone goal, rather they are meant to be combined with epidemiological measures to form summary measures (Essink-Bot and Bonsel 2002). Prevalence, incidence and duration of diseases are key components of epidemiological data that is required to calculate the DALY. The WHO calculates years of life lost due to disability (YLD) as a function comprised of $I \times DW \times L$ where $I$ is the number of incident cases for cause *c*, age *a*, and sex *s*; *DW* equals disability weights for cause *c*, age *a*, and sex *s* and can be thought of as severity of a disease; and *L* is the average duration of the case until remission or death in years (Prüss-Üstün, Mathers et al. 2003).

To determine the DALY, the YLD measure is added to the years of life lost due to premature death (YLL) function comprised of *N* x *L* where *N* is the number of deaths due to cause *c* for a given age *a* and sex *s* in year *t*. *L* (*s*, *a*) is a standard loss function describing years of life lost for a death at age *a* and sex *s* (Prüss-Üstün, Mathers et al. 2003). The DALY becomes a single number describing the overall health loss of a given disease or disease group that can be broken down by age, sex, and region (WHO 2002).

The following chapters explore derivation of disability weights, application of the disability weights and DALact metric with prevalence data from sample farms, and future discussion of the DALact metric and dairy farms.

# CHAPTER 2: MATERIALS AND METHODS: DISABILITY WEIGHTS AND EXPERT OPINION SURVEY

## *2.1 Introduction*

The World Health Organization (WHO) uses a disability-adjusted life year (DALY) metric to estimate the global burden of disease for hundreds of diseases and injuries worldwide. Due to the fragmented and inconsistent nature of disease and mortality records around the world, standardized and comparative information about ill-health and death are needed. The WHO's Global Burden of Disease (GBD) study was initiated primarily to identify those risk factors and diseases that cause loss of health and early death. A secondary goal of the GBD study was to quantify economic losses due to ill-health and early death and apply the acquired information on economic inefficiency to public health policies to support resource allocation. Disease burden is an important public health topic and needs to have a clear and concise system that assists policymakers in their decisions on global health strategies.

Similar to problems a growing human population faces, as dairies continue to consolidate and grow in size the need for standardized measures across farms is a necessary next step. Comparable to the GBD study's primary goal, the dairy industry's main objective should be reducing disease and death rates of cows. A study by Norgaard et al. (1999) found that increased mechanization resulting in physical environmental changes due to a growing herd size increased dairy cow mortality (Norgaard, Lind et al. 1999; McConnel 2010). Factors that affect death and disease on dairy farms are multi-factorial. Weather, lactation status, physical housing, animal handling, feed intake, reproductive status, and corral management are just a few influences that are involved in the development of diseases and subsequent death on dairy farms.

Typical dairy farm record keeping is lacking in specificity of diseases. To properly assess and make appropriate changes to management practices regarding diseases, more detailed information needs to be recorded on individual cows and this information needs to be analyzed in a novel way similar to the DALY metric. Without this information, dairymen and veterinarians are left to estimate the costs of disease in terms of disease prevalence and have no accurate assessment of the impacts of morbidity and mortality on animal stewardship, living conditions, health system effectiveness, and associated economic opportunity costs.

The DALY estimates time lost due to ill-health and early death (Murray and Acharya 1997). It is comprised of three components: years of life lost due to disability (YLD), years of life lost to early death (YLL), and a set of disability weights that describe the severity of the disease (Murray and Acharya 1997). YLLs estimate the number of deaths due to a given disease multiplied by the standard life expectancy at age of death, in years (WHO 2015). YLDs estimate the incidence cases of a disease multiplied by the average duration of the disease in years multiplied by a disability weight (WHO 2015). These two metrics are added together to create the DALY metric.

Disability weights are a key element of the DALY. Disability weights initially were determined by a panel of health experts who estimated the overall well-being of a person afflicted with a given disease. The panel ranked the severity of the disease on a person's physical, mental, and social functioning on a scale of zero (no adverse effects) to one (death) (Stouthard, Essink-Bot et al. 1997). Each panel member's estimate was then combined into one value for a given disease to yield a disability weight.

Dairy disability weights are also vital to the development of the disease-adjusted lactation (DALact) metric. Although the disease variables are different than what humans assess, the principle is the same. Standard severity of disease scores must be established and combined with incidence, prevalence, and duration of disease to calculate a DALact metric. In order to obtain disability weights for dairy cattle diseases, an expert opinion survey was created to develop severity of disease scores. The concept of a survey is borrowed from the WHO expert opinion survey regarding human illnesses and injuries. Each expert weighs the severity of a given disease or injury on a scale from one (complete health) to ten (death). For the purposes of this survey, respondents were asked to rank a minimum, maximum, and most likely severity to give an overall range of the scope of the acute disease process. These rankings for each disease allowed for disability weights to encompass the range of disease severities that occurs among dairies. For example, some farms might tend to have very severe metritis cases (a post-partum uterine infection) that could be ranked five, seven, and nine for minimum, most likely, and maximum, respectively. Other farms may have mild cases of metritis as an overall disease with subsequent ranking of two, three, and four for minimum, most likely, and maximum. The overall objective of this survey was to establish disability weights to be applied to on-farm disease prevalence data to generate estimates of time lost due to active phases of disease.

### *2.2 Expert Selection*

National and international dairy experts were invited in August, 2014 to participate in our survey through professional organizations (American Association of Bovine Practitioners), dairy industry publications and conferences (Progressive Dairyman, Australian Cattle Veterinarians Annual Conference, World Buiatrics Congress, and Academy of Dairy Veterinary Consultants), industry contacts, and word-of-mouth.

*2.3 Survey Outline*

Surveys were emailed to participants using email listserves from participating collaborators. Participants were asked to follow an online link to the survey on Qualtrics that kept respondents anonymous (Qualtrics, LLC, 2015). The survey was divided into four sections: 1) background information and demographics; 2) severity of disease scoring; 3) likelihood of culling; and 4) cost of disease. (Appendix A).

Section one asked participants for their primary location of practice. It also asked for scope of experience by professional title and years working in the dairy industry. Section two was the main portion of the survey that queried participants about the severity of select diseases in order to capture disability weights for the DALact. This section included 12 common dairy cow diseases and an example of how to score each disease (scale of 1-10, one equals least impact, 10 equals euthanasia or death). The health problems encompassed standard diseases and injuries that are recorded in on-farm databases and included: calving trauma, diarrhea, ketosis, lameness (hoof only), left displaced abomasum, mastitis, metritis, milk fever, musculoskeletal injury (leg, hip, back), pneumonia, retained placenta, and right displaced abomasum. Participants were asked to score severity of diseases with a minimum, maximum, and most likely impact on overall animal health and milk production based on their experience with individual animals. A hypothetical disease scenario was provided for pink eye with example scores of 1 (least impactful/minimum), 2 (most likely), and 4 (most impactful/maximum).

Section three requested that participants classify the minimum, maximum, and most likely percent of animals likely to be culled due to a given disease on dairies. This section was divided into five categories based on days in milk (DIM) and pregnancy status of the animals.

DIM and pregnancy status represent two of the most crucial variables that are considered when deciding to cull an animal. Other variables are included in the decision making process, such as age, disease history, attitude and behavior, milk output, and body condition. These variables are important, but difficult to categorize effectively in a survey. However, DIM and pregnancy status are ultimately two of the most important that are considered because an animal's value is placed heavily on her ability to produce healthy calves and thus continue producing milk within a biologically and economically productive time frame. The five categories were: 1) less than 60 days in milk and not pregnant; 2) 60-200 days in milk and not pregnant; 3) 60-200 days in milk and pregnant; 4) greater than 200 days in milk and not pregnant; 5) greater than 200 days in milk and pregnant. Ranked diseases and injuries included in each category were based upon biologically sound reasoning. For example, calving trauma was not included in the category "greater than 200 days in milk and pregnant" because it is not biologically reasonable for calving trauma to be a recent issue given the lactation and reproductive status. Alternatively, a disease such as mastitis was included in all categories because it is biologically plausible that an animal can suffer from mastitis throughout her lactation, regardless of pregnancy status.

The fourth and final section asked participants to rank the top five most expensive diseases on a dairy. Thirteen common dairy cow diseases and injuries were included: abortion, calving trauma, diarrhea, ketosis, lameness (hoof only), left displaced abomasum, mastitis, metritis, milk fever (hypocalcemia), musculoskeletal injury (leg, hip, and back), pneumonia, retained placenta, and right displaced abomasum. A ranking of one indicated it was the least costly of the most expensive issues and a ranking of five indicated it was the most expensive disease or injury on the dairy.

*2.4 Implementation of Survey*

The survey was available from August, 2014 through June, 2015. It was initially distributed to over 2,000 potential respondents via email, colleagues, and then through other media and conference outlets.

*2.5 Analysis of Responses*

Responses were downloaded into Microsoft Excel (2010) and analyzed by section. Within the Severity of Disease section, descriptive statistics and graphical analysis of experts' responses for each disease was performed. A Pert distribution was used to analyze expert opinions defined by minimum, most likely, and maximum values. A Pert distribution is similar to a beta distribution as defined by Van Hauwermeiren and Vose (2009). It fits a probability distribution around an expert's estimates to reflect uncertainty and variability in each group of responses (minimum, most likely, and maximum) and then an overall combined distribution was created by randomly selecting values from each distribution numerous times. This is an applicable model to use for the experts' opinions as we expected there to be a certain level of variability in the severity of diseases based on individual respondent's personal experience. Ultimately, the Pert distribution utilized the values from a respondent to determine the impact, variability and uncertainty within their answer.

The following formula was used to define each set of expert opinions per disease (minimum, maximum, and most likely):

$$\text{Pert}(a,b,c) = \text{Beta}(\alpha_1, \alpha_2) * (c-a) + a$$

Where:

$$\mu = \frac{a + 4 * b + c}{6}$$

$$\alpha_1 = \frac{(\mu - a) * (2b - a - c)}{(b - \mu) * (c - a)}$$

$$\alpha_2 = \frac{\alpha_1 * (c - \mu)}{(\mu - a)}$$

As defined by: a = minimum, b = most likely, c = maximum

Individual distributions were combined using a discrete distribution in the form of Discrete ({xi}, {pi}), where {xi} are the expert opinions for experts i = 1 to n and {pi} are the weights given to each expert opinion. In this case equal weighting was used (Van Hauwermeiren and Vose 2009).

Due to a lack of data due to incomplete responses for Sections Three and Four (Likelihood of culling and Cost of Disease), the data from these sections were not analyzed.

*2.6 Survey Results*

The survey was completed by 184 respondents. Of those responding, there was a 58% drop out rate. Most drop out occurred during the Likelihood of Culling section. Of the 184 respondents, 137 provided identifying professional information (74.4%). There were 21 dairy producers/owners (15%), 8 managers (6%), and 108 veterinarians (79%). A total of 96 respondents provided complete estimates for the severity of diseases listed in section two of the survey. Average years working in the dairy industry was 20.3, with a minimum of 1 year, maximum of 50 years, and a median of 20 years. Nationally, responses came from: Arizona, California, Colorado, Idaho, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, New

Mexico, New York, Ohio, Pennsylvania, Texas, Vermont, Virginia, Washington, and Wisconsin. Internationally, responses came from: Australia, Austria, Canada, France, Germany, Hungary, Mexico, New Zealand, and Spain.

Based on the identifying information provided by respondents, it was concluded there was adequate experience based on years in the industry or professional experience related to dairy cow diseases and death management to confidently accept responses as “expert.” The mean and median years of experience as reported by experts were 20.4 and 25.5 years, respectively.

The mean and median of minimum, maximum, and most likely severity score results from the expert opinion survey are presented in Table 1. The average of the minimum, maximum, and most likely median was calculated to use as the disability weights in the DALact metric (Table 1).

**Table 1: Minimum, maximum, most likely mean and median severity scores**

| | Mean | | | Median | | | |
|---|---|---|---|---|---|---|---|
| **Disease** | **Min** | **Max** | **Most likely** | **Min** | **Max** | **Most likely** | **Average** |
| Calving Trauma | 2.73 | 9.38 | 4.88 | 2.00 | 10.00 | 5.00 | 5.67 |
| Diarrhea | 1.77 | 7.41 | 3.33 | 1.00 | 8.00 | 3.00 | 4.00 |
| Ketosis | 2.31 | 7.48 | 4.17 | 2.00 | 8.00 | 4.00 | 4.67 |
| Lame (hoof only) | 2.60 | 8.41 | 4.89 | 2.00 | 9.00 | 5.00 | 5.33 |
| Left Displaced Abomasum | 3.77 | 8.52 | 5.23 | 4.00 | 9.00 | 5.00 | 6.00 |
| Mastitis | 2.35 | 9.38 | 4.57 | 2.00 | 10.00 | 4.00 | 5.33 |
| Metritis | 2.43 | 7.97 | 4.22 | 2.00 | 8.00 | 4.00 | 4.67 |
| Milk Fever | 2.59 | 8.20 | 4.06 | 2.00 | 10.00 | 4.00 | 5.33 |
| Musculoskeletal Injury | 3.35 | 9.22 | 5.82 | 3.00 | 10.00 | 6.00 | 6.33 |
| Pneumonia | 3.36 | 8.84 | 3.49 | 3.00 | 10.00 | 5.00 | 6.00 |
| Retained Placenta | 2.05 | 6.70 | 3.49 | 2.00 | 6.00 | 3.00 | 3.67 |
| Right Displaced Abomasum | 4.48 | 9.25 | 6.57 | 4.00 | 10.00 | 7.00 | 7.00 |

*2.7 Descriptive Graphs of Results*

The following disease severity results (Pert distribution) were calculated using R (The R Foundation for Statistical Computing, 2014).

Calving Trauma expert opinion results are shown in Figure 1. The dashed red line represents combined repeated sampling of the individual estimates. The y-axis includes the densities of the ranges of responses between minimum, maximum, and most likely. Higher, narrow peaks for an individual line (increased density), represents less variability within an individual's impact assessment. Each line represents an individual response's variability and uncertainty as modeled by the Pert distribution. While at first glance, the combined distribution (dashed line) shows a relatively normal distribution with the minimum at one, maximum at 10 and mean at roughly five, there is marked variation between the individual respondents which indicates lack of agreement by experts, as evidenced by many different opinions (lines) across the x-axis. This graph also indicates that impact varies greatly among respondent's experience with calving trauma, evidenced by the different ranges of the individual lines, i.e. some lines have narrow peaks while others have broader peaks. Therefore, the severity of a calving trauma varies greatly among respondent's experience.

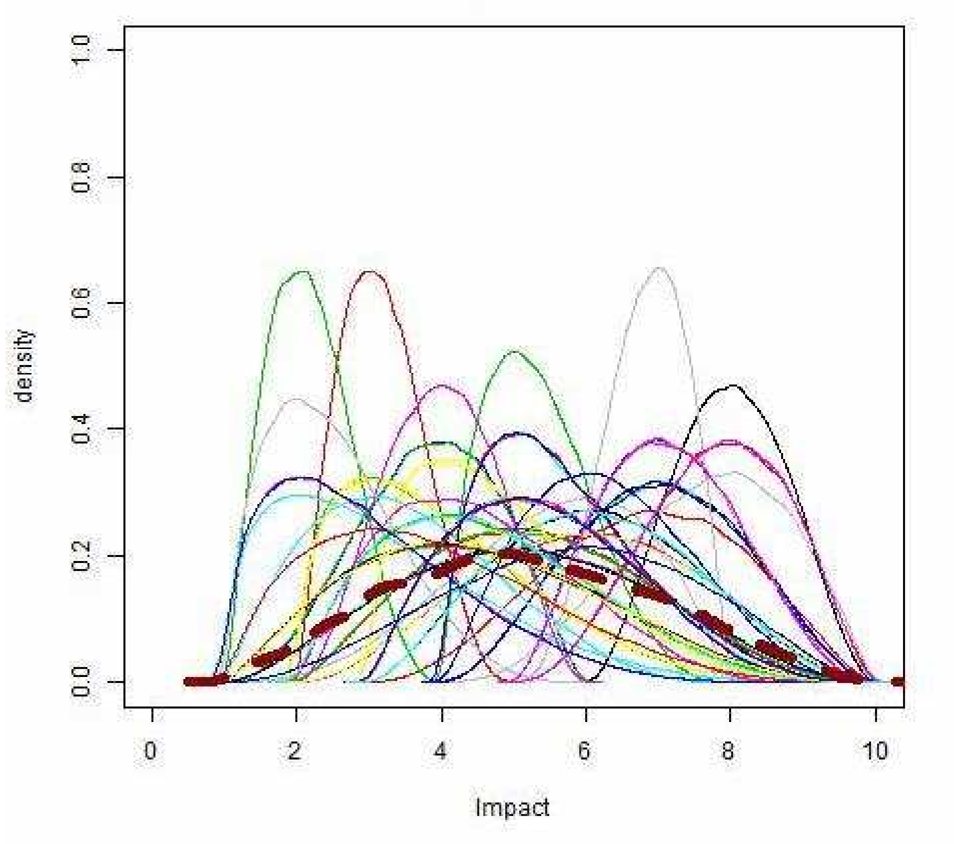


Figure 1. Calving trauma Pert distribution

Figure 2 shows results for diarrhea. This graph shows much more agreement among the experts. Diarrhea severity scores overall had narrow peaks indicating variability and uncertainty among respondents were low. Respondents tended to agree that the best case scenario and worst case scenario of a case of diarrhea had a relatively low impact, as evidenced by the overall left shift and tightly bundled group of lines on the x-axis.

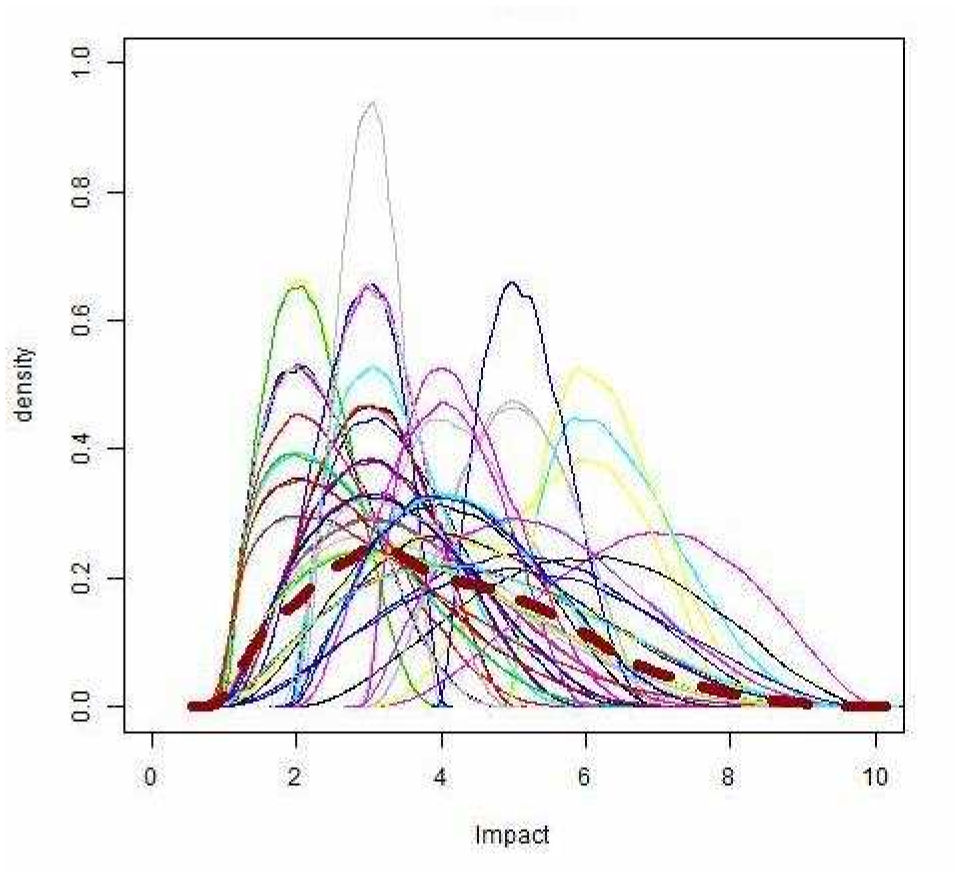


Figure 2. Diarrhea Pert distribution

Figure 3 demonstrates most experts tended to agree ketosis has a relatively narrow range of severity in most cases on dairy farms. However, variability across respondents appeared to be high as evidenced by multiple peaks across the x-axis and no discernable grouping. In general, respondent's experiences varied with regard to the impact of ketosis on cows, but the overall indication was that regardless of its severity the impact of ketosis appears to be relatively constricted.

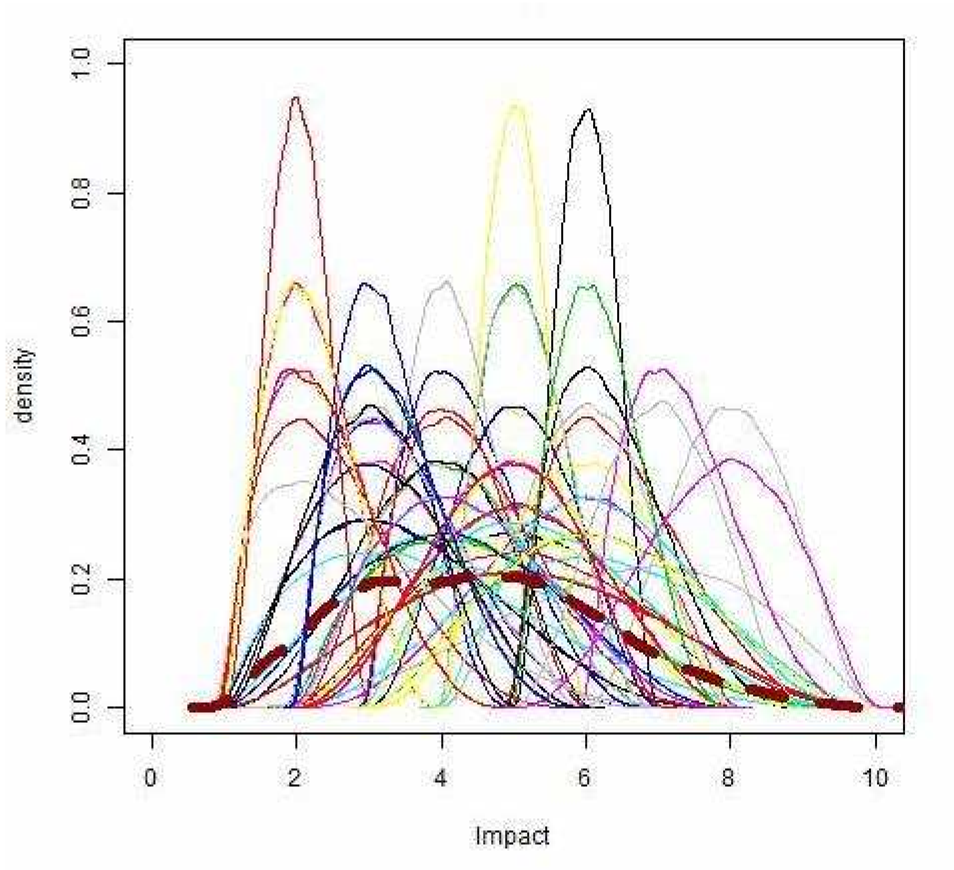


Figure 3. Ketosis Pert distribution

Figure 4 reveals lameness had a similar distribution to ketosis. Variability among respondents was high, evidenced by many individual lines across the scale. Uncertainty regarding the level of impact was also high as shown by multiple narrow peaks as well as broad peaks. Experiences with lameness clearly differed across farms and respondents.

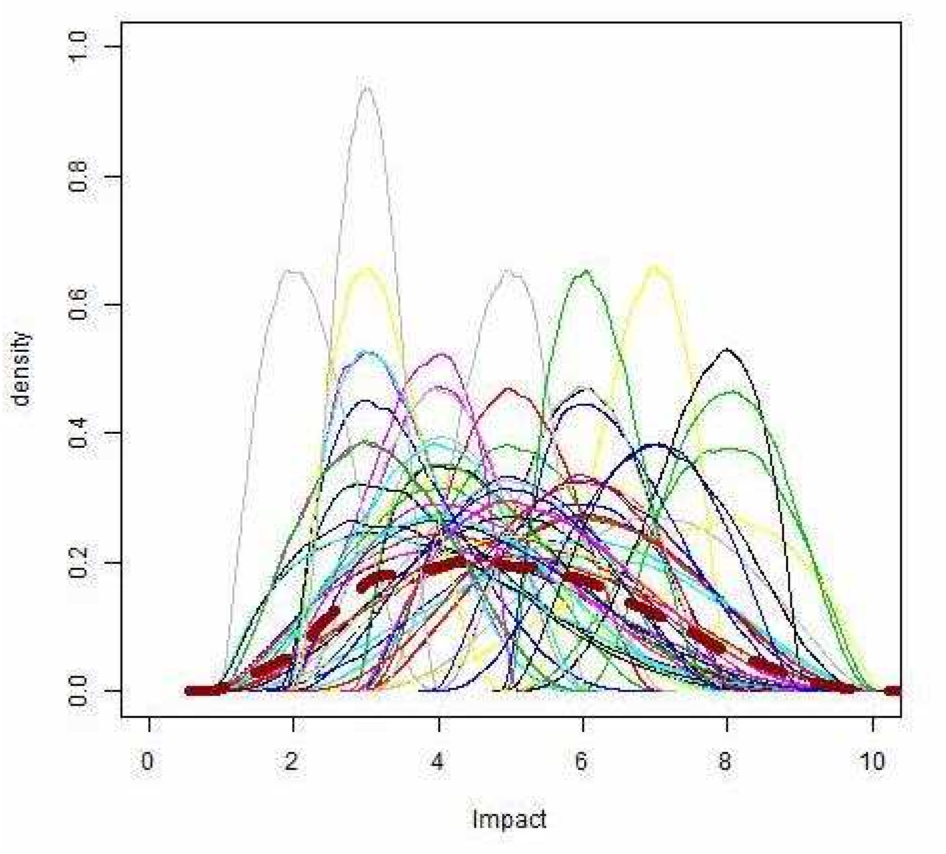


Figure 4. Lameness Pert distribution

The left displaced abomasum severity graph (Figure 5) shows a relatively normal (bell shaped curve) combined distribution with a slight shift to the right indicating increased severity. However, the higher peaks (increased densities) of the individual lines indicate there is some agreement among respondents that the impact of a left displaced abomasum is either of medium severity or high severity, but unlikely to be spread across both.

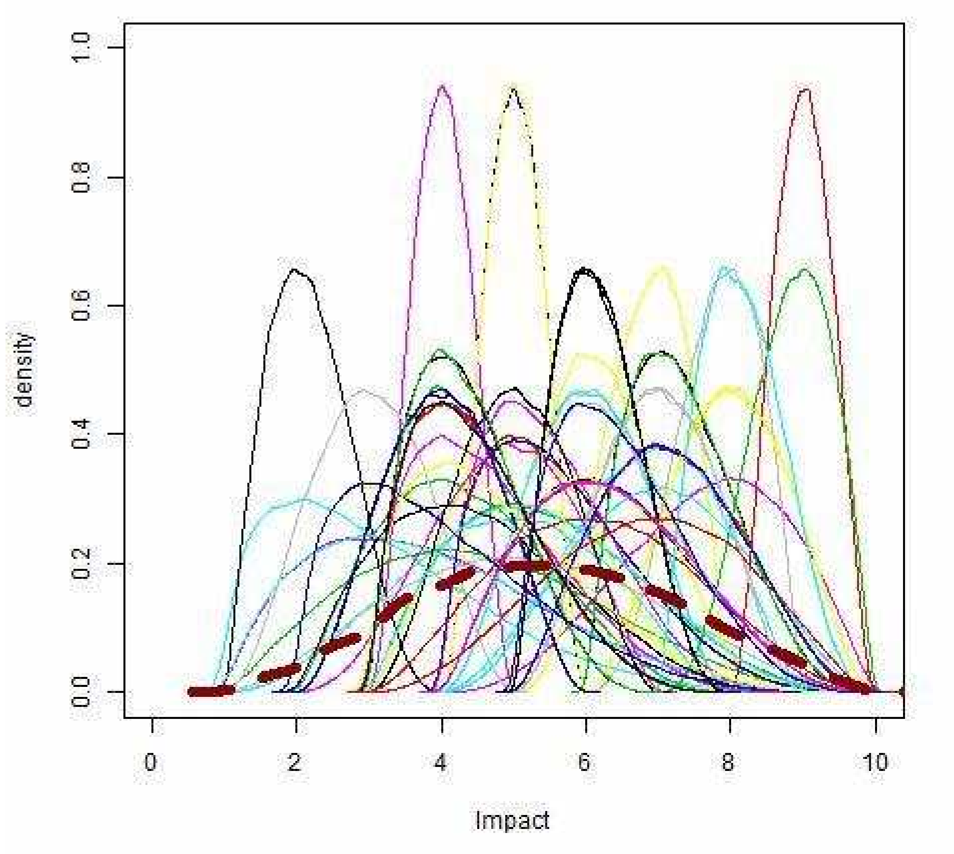


Figure 5. Left displaced abomasum Pert distribution

The results for mastitis were quite varied (Figure 6). The combined distribution follows a relatively normal bell shaped curve where minimum is one, maximum is 10 and most likely is around five. However, respondents were uncertain about the severity level of mastitis. Opinions and experience regarding this disease clearly vary based on the numerous, broad lines across the x-axis.

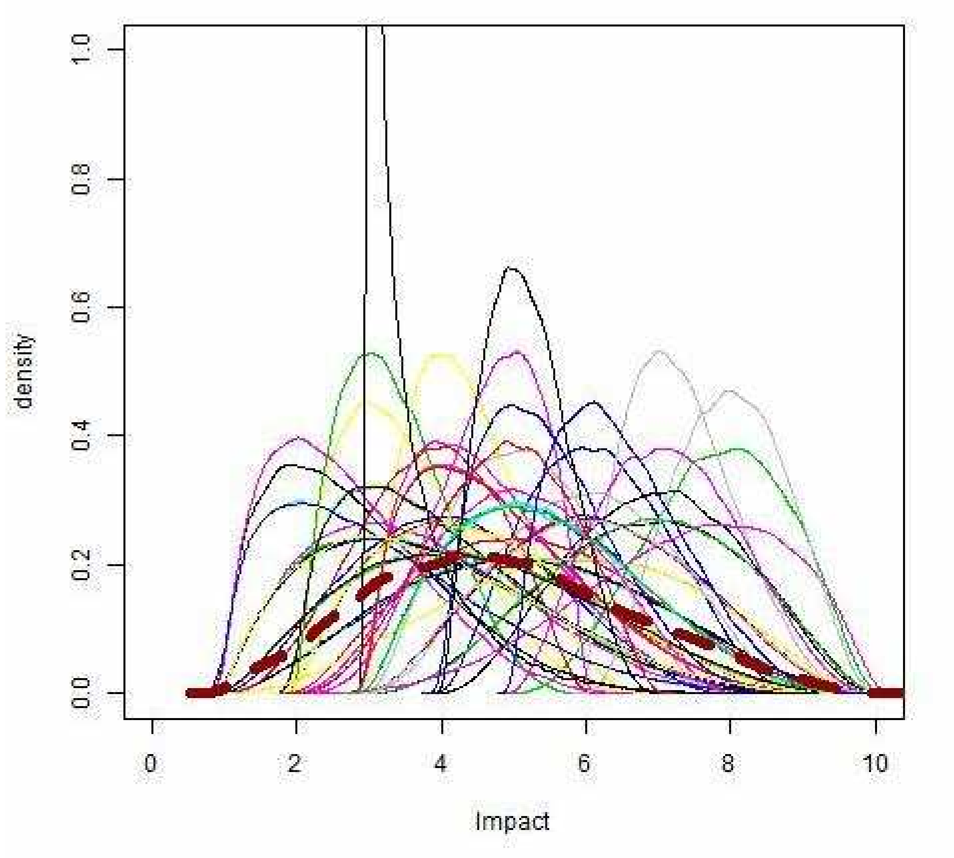


Figure 6. Mastitis Pert distribution

The opinions for metritis were also varied with a slight left shift indicating a lower overall severity level (Figure 7). The tall, sharp peaks indicate some experts were fairly certain (and agree) metritis has a narrow range of severity. On the other hand there were some experts that felt metritis has a very wide range of severity as evidenced by the dense broad peaks.

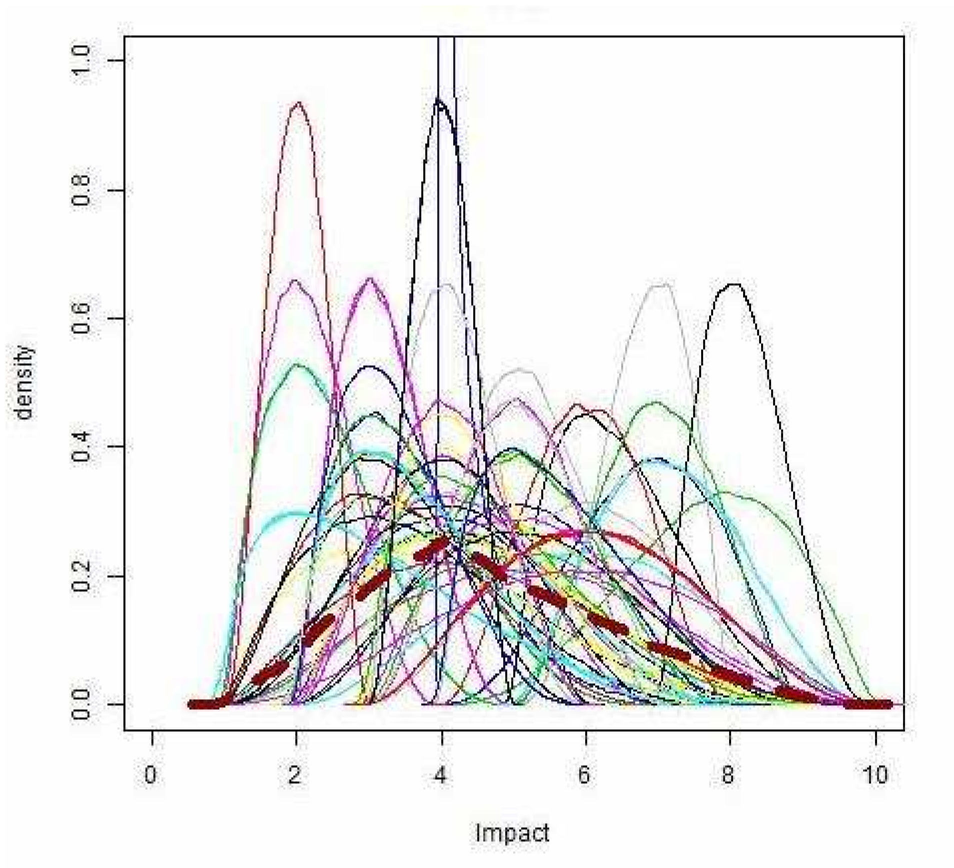


Figure 7. Metritis Pert distribution

Similar to metritis, milk fever severity scores trended toward being less traumatic with narrow ranges for minimum and maximum on the left end of the scale (Figure 8). However, the certainty and variability among the respondents is marked in this case, indicating different outcomes regarding milk fever on farms.

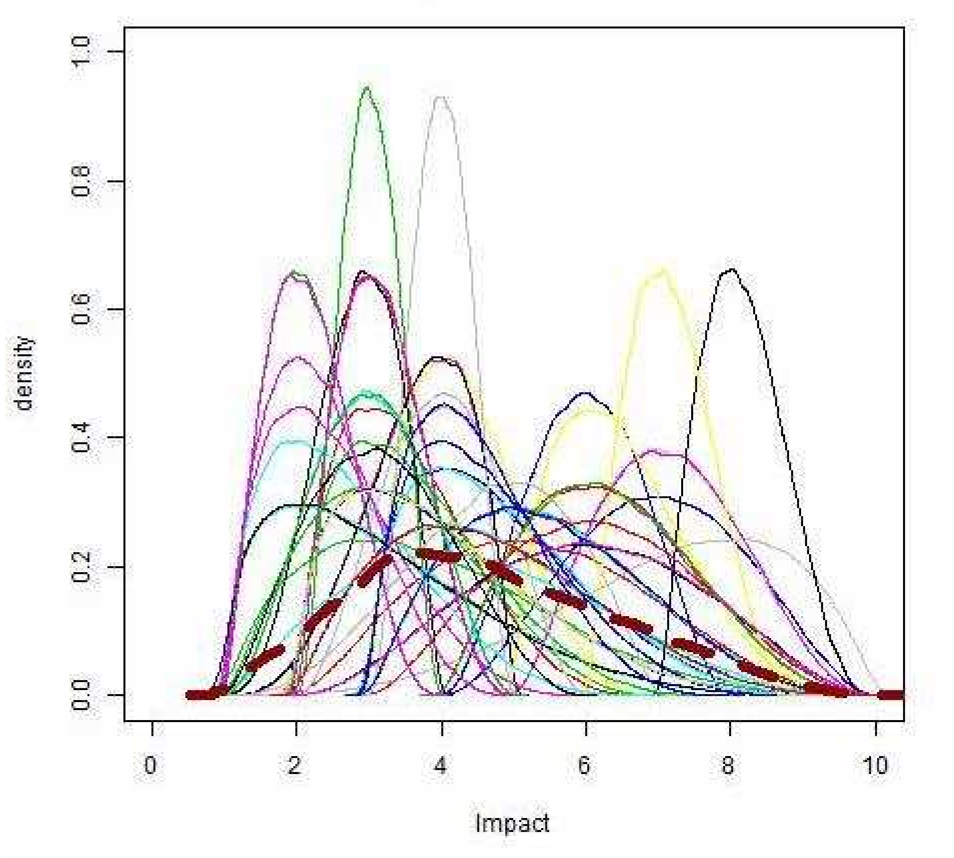


Figure 8. Milk fever Pert distribution

Musculoskeletal injury had a definite skew to the higher end of the severity scale (Figure 9). Wider ranges for minimum and maximum were more apparent here with fewer narrow peaks than in other diseases. Experts generally agreed an injury could either be very minor (a one on the severity scale) or terminal (a 10 on the severity scale). While there appeared to be some agreement regarding the range of severity of an injury, variability of responses was still high and therefore experience was varied.

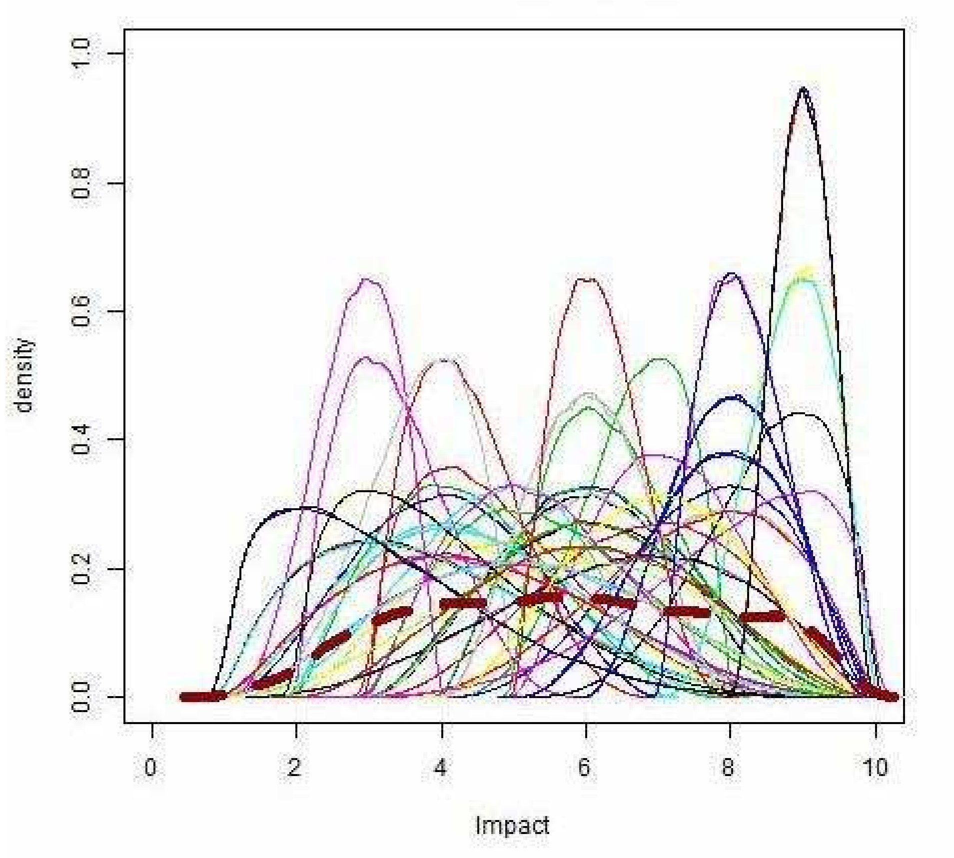


Figure 9. Musculoskeletal injury Pert distribution

Pneumonia severity scores follow a relatively normal (bell shaped curve) combined distribution (Figure 10). The range between minimum and maximum fluctuated between wide and narrow ranges across the distribution. Respondents indicated pneumonia severity varies greatly among cases and farms. Uncertainty among respondents was high as evidenced by variable density peaks and no discernable uniformity in width on the x-axis.

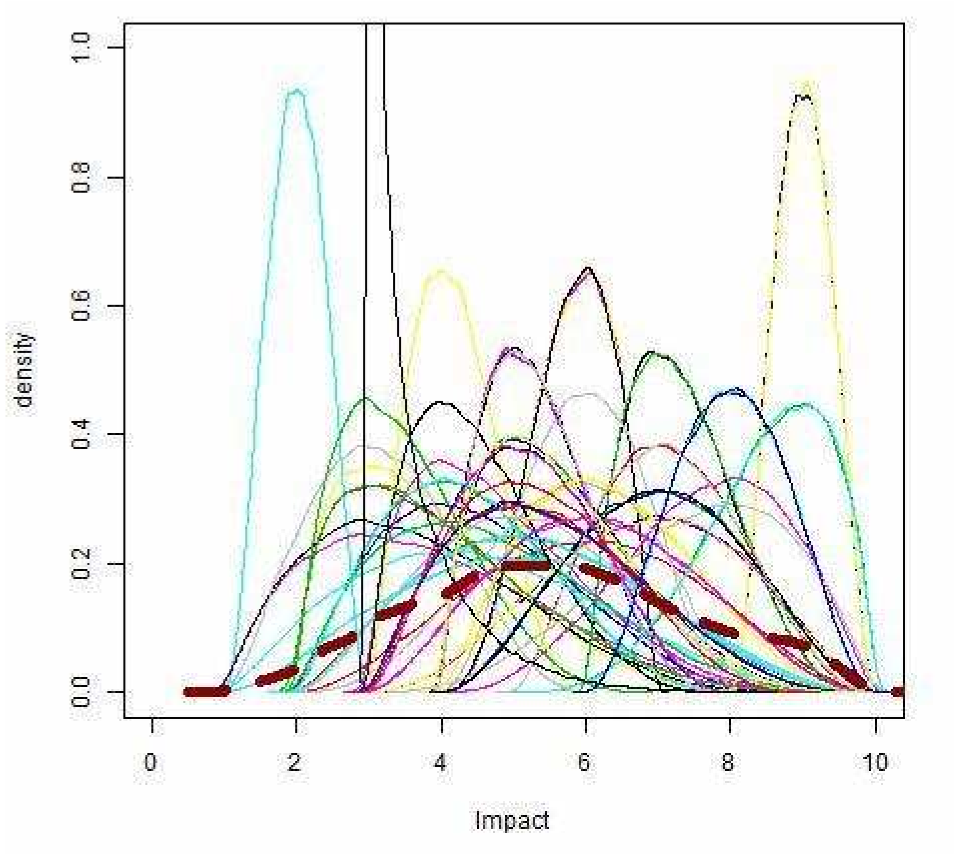


Figure 10. Pneumonia Pert distribution

Right displaced abomasum severity scores trended toward the more traumatic end of the scale (to the right) (Figure 11). The ranges between minimum and maximum were relatively variable for RDA with a mix of both broad and narrow ranges. However, the minimum scores generally fell between two and four, and the maximum scores fell between eight and 10, creating a right shift of the data. Respondents were in agreement (variability was low) that an RDA in a dairy cow is a relatively serious disease. Uncertainty was also low, as evidenced by the density of the individual lines toward the right.

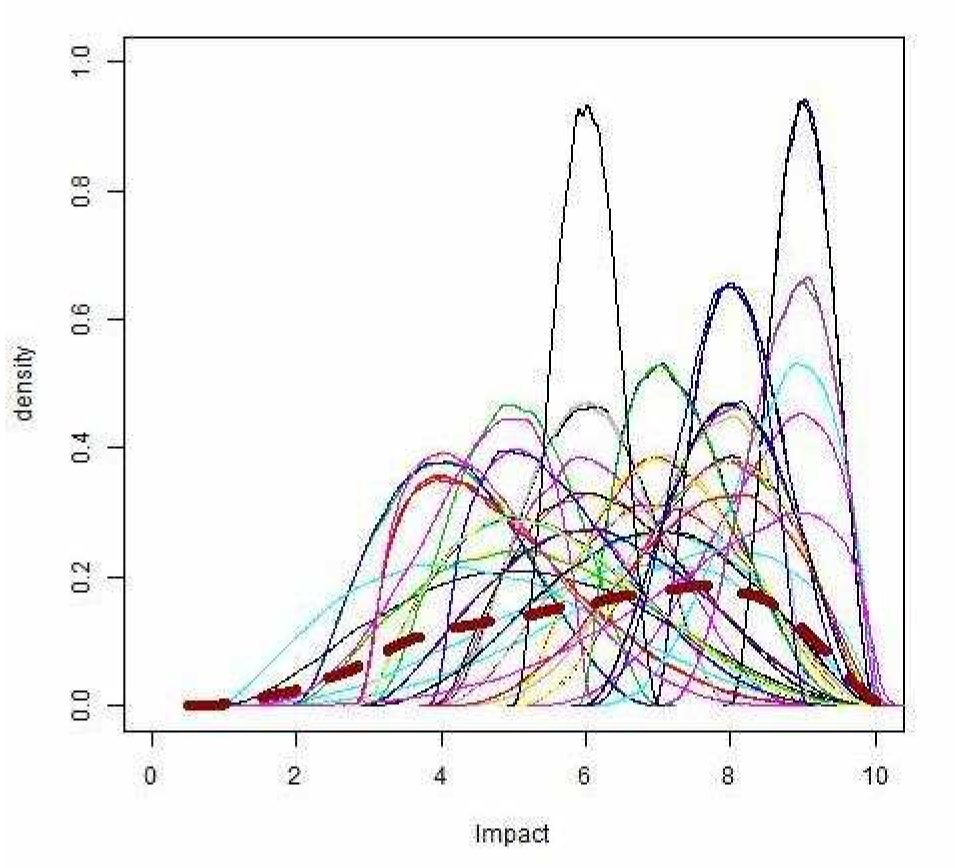


Figure 11. Right displaced abomasum Pert distribution

Retained placenta severity scores trended toward the less traumatic (left) side of the graph (Figure 12). The peaks were also narrow with very few wide peaks indicating a small range of impact for a retained placenta in dairy cows. Here, respondents were generally in agreement, with low variability among reported experience, and low uncertainty as evidenced by density of the individual responses lines on the left side of the graph.

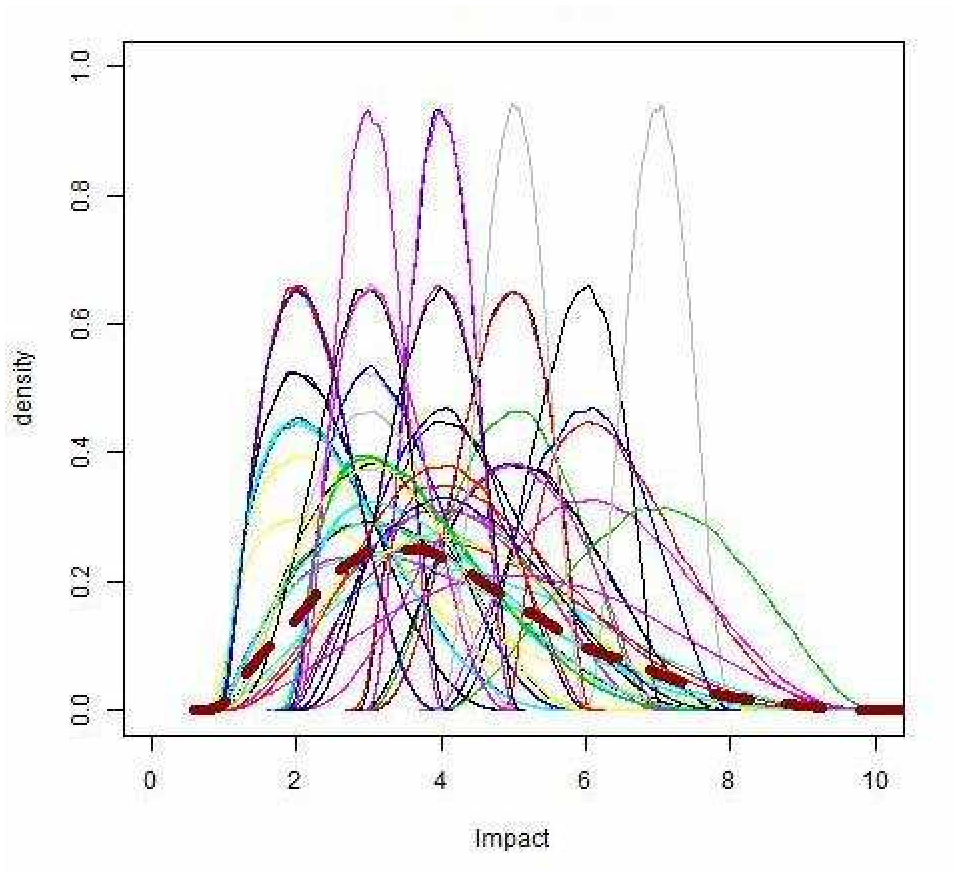


Figure 12: Retained placenta Pert distribution

*2.8 Discussion*

The Dairy Expert Opinion Survey was distributed to over 2,000 industry leaders in multiple countries including Australia, the United States, Germany, Canada, and the Netherlands. The survey included three main parts. These parts consisted of a severity weighting portion, a likelihood of culling portion and an estimated cost of disease portion (Appendix A). The disease severity portion was the main focus of the survey and aimed to capture the severity of a disease relative to health and death. The likelihood of culling portion aimed to assess experts' opinions on the likelihood of an animal leaving the farm due to human intervention. The final portion estimated the cost of disease and asked participants to rank diseases in order of least to most expensive. Although the likelihood of culling and the cost of disease portions of the survey were not routinely answered and ultimately discarded, the section quantifying disease severity provided useful data for the development of dairy disability weights.

Disability weights in the WHO's DALY study arose from a desire to have a standardized disease severity scale worldwide. Without a standard severity measure, diseases across the world are viewed on a varied scale based on the current public methods. Whereas death is easily categorized (alive or dead) in any part of the world, non-fatal outcomes are not (Murray and Lopez 1996). Diseases burden individuals differently: from the source of the illness to the impact on the person's wellbeing and how the surrounding support system reacts to the issue (Murray and Lopez 1996). Thus, a measure that defines time spent in less than perfect health can be combined with mortality statistics for the purposes of evaluating disease burden across a global scale. Akin to the distinct classification of death in medical records, disability burdens need to be measured, defined, and valued in a way that captures the full disorder of the disease on an individual (Murray and Lopez 1996).

Developing aspects of the DALY metric for direct application on dairy farms was the goal of this project. Due to differences in human and dairy populations, some components of the DALY need to be revised in order to be useful. However, some components can be modeled very closely to the DALY in development and application, such as disability weights. Disability weights measure the severity of a disease in relation to health versus death. The WHO has modified disability weights over the course of a number of years as they are a complex measure that strives to place a numerical value on the mental and physical ramifications of a disease. This complexity was found to hold true in the derivation of disability weights for the DALact. Experts were asked to determine the level of severity on dairy cows in varying stages of lactation and pregnancy status based on their experience on dairy farms. Although there were a few diseases that were easily identified for a lower or higher level of severity, many of the disability weights indicated experts had a difficult time discerning a clear level of severity for a given disease.

Calving trauma disability weights indicated respondents' experience is varied. One component of a successful assisted calving depends on the proper training and capability of the person aiding the animal. When a calving trauma is handled successfully, there is a high probability of full recovery for a cow, but if it is unsuccessful, the impact on the animal can be quite severe. Calving trauma can be associated with subsequent periparturient conditions and this may be a factor under consideration when assessing the severity. Similar to calving trauma, a relatively normal (bell-shaped) combined distribution was also seen on the graph for lameness. While lameness may result from a specific disease (e.g., sole ulcer, foot rot, hairy heel wart), lameness is often the term used when classifying general hoof and leg issues of dairy cows. A normal distribution in this case perhaps results from a non-specific description of lameness used in the survey. Without specific diseases attached to the lameness description, severity is difficult to gauge. For example, the overall health impact of an untreated foot rot can vary greatly from a hairy heel wart in dairy cows.

Experts' opinions on diarrhea, milk fever, and retained placenta all had a slight skew to the left of the graph indicating the overall scores were on the lower end of the impact scale. This validated common thinking on dairies that episodes of diarrhea, retained placentas, and milk fever are manageable and typically not severe on their own. However, precursors and subsequent health problems related to these diseases may cause severe impacts on an animal's health. For example, milk fever is easily treated early in the disease process but when poorly managed can be an underlying cause for subsequent periparturient conditions or even lead to prolonged recumbency and death. These considerations may have influenced those respondents whose answers tended towards the severe end of the severity scale.

Ketosis and left displaced abomasum graphs had relatively narrow peaks indicating that experts felt the minimum, maximum and most likely severity of these two diseases are similar. Ketosis, and specifically subclinical ketosis, is often undiagnosed on dairies but a well-known disease. In early lactation cows, it can lead to further complications such as displaced abomasum, metritis, poor reproductive performance, and reduced milk production (McArt, Nydam et al. 2013). Experts might have taken into account similar considerations for this disease as for diarrhea, milk fever, and left displaced abomasum; the conditions and problems that occur as sequelae to these diseases are sometimes worse than the acute phase. Those considerations are hard to articulate when ranking disease severity but the narrow peaks (increased density) of the individual distributions indicate experts believe that the disease is either mild or severe but rarely both.

Mastitis and pneumonia had wider peaks than some of the other graphs. These diseases can manifest a wide range of severity in dairy cows. On the one end, an environmental mastitis case can present as a relatively mild disease. On the other end, a *Mycoplasma bovis* infection can cause severe respiratory damage, clinical mastitis, a tremendous drop in milk production, and possibly lead to death or euthanasia (Pothmann, Spergser et al. 2015). Pneumonia can have similar results. The expert opinion graphs reflected the potential variety in mastitis and pneumonia cases. Without more specific details describing the cases, responses were generally uncertain and varied, as evidenced by the wide range of responses.

Musculoskeletal injury and right displaced abomasum were two graphs that skewed to the right. Both of these diseases often have severe consequences. This opinion was shared by many of the respondents as demonstrated by lines with increased density and skewing toward the right of the graph. A hip or back injury in a large animal typically has a terminal outcome. A right displaced abomasum if not detected and corrected immediately, can be terminal. The graphs supported expert's common opinion about the severity of these two diseases.

The question asked of respondents regarding disease severity revolved around the impact of a given disease on overall dairy cow health and milk production. The questionnaire asked experts to rank a minimum, maximum and most likely impact of 12 different diseases. The health events were chosen based on their common and consistent recording on most dairies. However, to offer a bird's eye view of disease severity relative to time lost, health events were chosen as general events. These disability weights were generated from varied perspectives and experiences from multiple industry experts. A median of the most likely was chosen as one point for calculation in the DALact and these points inherently express the variability that occurs on dairies and in specific cases. In order to reduce that variability and have more accurate, specific disability weights, more precise disease descriptions would need to be developed. Lameness and mastitis, for example, would be events that could be broken down to more distinct descriptions.

The overarching goal of this project was to develop a better assessment of time lost, and therefore the opportunity costs of diseases and death on dairies. In order to accomplish this goal, a novel way of evaluating health records was developed. The DALact metric with its requisite disability weights will attempt to establish a more in-depth method to analyze dairy records and the impact of disease on animal well-being and economic opportunity costs. The following chapter evaluates the use of the DALact metric on farms using standard health records in an effort to prioritize health interventions based on time and expand the discussion of animal health to view profits and losses in light of the quality and length of life.

# CHAPTER 3: PREVALENCE DATA AND DALACT CALCULATION

## *3.1 Introduction*

Dairy cow morbidity and mortality in the United States are concerns that not only damage farms financially but also tarnish the industry's reputation. As studies continue to investigate the increase in dairy cattle mortality and morbidity, animal welfare becomes a larger concern to the dairy industry (Thomsen and Houe 2006; McConnel, Lombard et al. 2008; Shahid, Reneau et al. 2015). These reasons become the main focus for increased health monitoring and standards in recording and interpretation of data on dairy farms. Historically, records regarding disease and death on dairies have been inconsistent and definitions of health events typically do not follow a national standard (Kelton, Lissemore et al. 1998). Several Western European countries have advanced animal health recording systems and innovative animal monitoring systems that have been developed in response to public opinion, property shortage, and government pressures (LeBlanc, Lissemore et al. 2006). Development of a national standard of recording and analyzing dairy cattle health data has improved in the U.S. in recent years; however, it is the opinion of many in the dairy industry and general public that more needs to be done to improve overall health, animal welfare, and financial stability of dairy cattle and farms (Esslemont 2011).

The World Health Organization (WHO) has developed a human-based assessment of productive time lost due to disease and injury. The WHO found there were inconsistencies in morbidity data, especially in developing countries (Stouthard, Essink-Bot et al. 1997). The reason for a standardized method of assessing disease across countries and regions was multi-faceted. The first reason was basic societal and cultural norms that strive for longevity. The second reason is economic. Public health officials rely on health data to make cost-effective disease intervention decisions. The disability adjusted life year (DALY) was developed to assess the global burden of disease and aid public health decisions and distribution of resources (Murray and Acharya 1997). The DALY uses a novel combination of components to determine productive time lost due to a given disease or injury. Disability weights are a component of the DALY, derived from health experts through a variety of tests and questions, that are used to standardize the mental, physical, and social severity of diseases along a scale of 0 (perfectly healthy) to 10 (death) (Stouthard, Essink-Bot et al. 1997). Additional components of the DALY are accurate disease duration definitions and morbidity prevalence data.

Global disease prevalence data can be lacking in specifics and completeness, especially in developing countries (Stouthard, Essink-Bot et al. 1997). Similarly, incomplete records are difficult to assess in the global dairy industry and are structured differently in certain regions (LeBlanc, Lissemore et al. 2006). Issues surrounding non-standardized health measures, both in humans and dairy cattle, require a novel way of looking at available records. Human productivity lost due to health events and early death has a societal, personal, and local impact. Evaluating and comparing those impacts on broader scale aid public health officials in decision making. Similar principles can be applied to dairy cattle records relating health and productive time lost to disease and premature death with the ultimate goals of healthy cattle and assisting overall herd management.

Assessing dairy health parameters in a similar fashion to the DALY by incorporating duration of disease, prevalence, and severity scores might reveal problematic areas previously missed through basic analyses of prevalence data. Typically, record assessments of health events, culling and dead cows are retrospective on farms and provide reaction based decisions as opposed to preventative (LeBlanc 2010). Establishing a novel method for assessing health problems could aid in preventative health management, improved animal welfare and health, and increased productivity of a farm. The goal of this study was to evaluate disease, death and culling prevalence data and compare them to a novel measure of time lost to death and disease on the farm: the DALact (Disease-adjusted lactation) metric.

### *3.2 Materials and Methods*

Dairy cow disease, death, and culling data from three similarly managed farms in Kansas housing approximately 9,000 Holstein cows in free stall barns were used in this study to develop the DALact metric. Similar to the human DALY, construction of the DALact metric required a comprehensive accounting of the expected Days Lost to Illness (DLI) as well as the Days Lost to Removal or Death (DLRD) such that the DALact = DLI + DLRD. As with the human DALY, the DLI must reflect the prevalence and duration of disease multiplied by a disability weight factor reflecting the severity of the disease. Unlike the human DALY, the DLRD must account for early death *or* forced removal and overcome deficits in mortality *and* removal records. Resulting estimates quantify the loss of functioning and well-being due to time lost to ill-health.

The data required to calculate the DLI and DLRD were accessed from herd data backups using Dairy Comp 305 (Valley Agricultural Software 2015). These data were uploaded on a monthly basis to a database for input into an Excel spreadsheet (Microsoft 2013) designed to capture pertinent information for this project. Data gathered from Dairy Comp 305 was obtained by using the EVENTS function. The specific formula used was: EVENTS ID LACT FDAT DIM CFDIF FOR LACT>0 FDAT=1/01/14-x/xx/xx\bsi where EVENTS=all herd events as defined by the farm using the system; ID=cow identification number in the herd; LACT=lactation number of animal; FDAT=fresh date of animal; DIM=current days in milk of animal;

CFDIF=calving difficulty at freshening (not available for all farms); for LACT>0=cows with lactation greater than 0, this excluded nulliparous heifers; FDAT=a freshening date that was between the project initiation (January 1, 2014) and the date at which data were being analyzed. Diseases of interest and removals (culled or died) were tracked for cows that freshened in the time frame described. The eight diseases of interest were: diarrhea, displaced abomasum, lameness, mastitis, metritis, milk fever, pneumonia and retained placenta. Clinical disease case definitions were developed by the dairy's veterinarian who trained farm managers to detect and identify each disease.

Information that was recorded for culled, died, and disease cows included identification numbers, fresh date, days in milk, lactation number, the reason for removal given by farm, removal date, and health events pertinent to our study with the date at which events occurred. A dead code was created and assigned to each cow that died during the study for all three dairies. This code assigned a given disease, if possible, as the main cause of death based on the farm's assignment or previous disease events. The participating farms had a system of attributing primary and secondary diseases as a way of gaining as much information as possible about an animal's death. The study farms did not utilize necropsies so the health history of the animals provided the only link to possible reasons as to why an animal died.

Dead codes included a two letter component that, if possible with the historical information provided, attributed the death to a single disease process. These codes incorporated all diseases recorded on farms, not just the eight that were tracked during this project. However, for analytic purposes, cause-of-death was attributed to one of the eight diseases of interest, or was classified as miscellaneous or unknown. Some animals did not have a single disease that could be attributed as the cause of death, because either not enough information was provided or there was an unknown cause that could not be distinguished without a necropsy. These cases were categorized as unknown and failed to provide useful information regarding underlying causes of death.

Dead codes were assigned using a variety of informative tools: the final disease process, other recent health events prior to the death, location of death, euthanized versus sudden death, as well as overall health of the animal including milk production, number of health events, calving difficulty (where applicable) and dry period characteristics. Each animal that died was looked at within the criteria listed above. Most often the primary cause of death as listed by the farm was determined after consideration of the rest of the information listed above. If the farm did not provide a reason for death and listed “unknown” as the cause, records for that animal were reviewed to try and determine a reasonable cause of death. In some cases, the underlying cause remained unknown. In other cases, deaths could be attributed to a specific disease process. For example, a cow was found dead in the free stall barn and was assigned an unknown cause of death due to a lack of external signs. Health records for this cow revealed she had recently moved out of the hospital the previous day after finishing treatment for pneumonia. In this case, it was reasonable to suggest this animal died due to pneumonia that was not treated properly or cured. However, accrediting a specific illness to an unknown death was infrequent.

Cows in this study were culled for 2 general reasons: economic or biologic (Fetrow, Nordlund et al. 2006). An economic cull was costing the dairy more money to house and feed her than she was returning in milk production income. A biologic cull was forced to leave because of a disease or injury. The reason for exit was due to a chronic disease event or an acute illness and the decision to remove the animal was mandatory rather than through consideration of profit or loss due to milk production.

The dairies involved in this project used a standardized culling system. Animals were removed from the farm if they were not meeting the breakeven point (milk production at a predetermined quantity indicating the cow was profitable for that farm) or they were removed due to an acute or chronic disease. The dairies used generic codes that were programmed into herd management software to designate reason for removal. These reasons ranged from specific diseases such as mastitis or lameness to generic "low production." Culling codes are usually singular generic conditions that give the *best available* reason for removing the animal and should be interpreted with caution because most animals leave the herd due to a combination of underlying issues (Fetrow, Nordlund et al. 2006; Pinedo, De Vries et al. 2010). Similar to developing a better dead cow coding system, the dairy industry should incorporate a more comprehensive coding system for culled animals if useful data is desired from farmers as to why their animals leave the farm (Fetrow, Nordlund et al. 2006).

This study ran for a 17-month period which provided an unequal risk period from freshening to disease or removal for individual cows. For example, an animal that calved on January 1$^{st}$ of 2014 (the initial criteria to be enrolled in the study) could have the opportunity to go through a full lactation (based on a 13-month calving interval) and be enrolled again in February of 2015. However, an animal that calved on May 1$^{st}$ of 2015 would only have 30 days of exposure to be included in the study and acquire diseases. Also, most diseases that were tracked were fresh cow diseases that occurred within the first 60 days of freshening. Therefore, the mid to late lactation diseases would be missed in a cow that was enrolled a month before the study ended. Consequently, some of the tracked diseases might have a higher prevalence than others, particularly the early lactation diseases because they occur at high frequency and more early lactation risk periods were included in this study (Goff and Horst 1997).

The same disease breakdown that was performed on all cows entered into the study was also performed on a subset of cows with completed lactation data (i.e. data from one calving to the next). Because cows that died or were culled were not included in the full lactation group, this subset of cows could be considered "survivors" who completed a full lactation within the study time period. Full lactation analysis was performed to look at the difference in prevalence of diseases when all cows had the same temporal risk of contracting any given disease throughout a lactation.

A key component of the DALact calculation is the disability weight. Disability weights describing the severity of diseases were derived from an expert survey. We considered experts in the dairy industry to be veterinarians, producers, and farm managers and invited participants via professional publications, dairy industry publications and conferences, contacts and colleagues. The survey queried participants on years of experience, professional title and location of main practice/farm. Respondents were asked to assign a minimum, maximum and most likely impact on overall cow health and production for 12 common dairy cow diseases. The scale ranged from perfectly healthy (0) to death or euthanasia (10). Diseases included were: calving trauma, diarrhea, ketosis, lameness (hoof only), left displaced abomasum, mastitis, metritis, milk fever, musculoskeletal injury (leg, hip, back), pneumonia, retained placenta, and right displaced abomasum. Diseases that were surveyed for disability weights were the only events able to be analyzed in the DALact.

A beta-Pert distribution was performed on respondent's answers (Van Hauwermeiren and Vose 2009). A PERT probability distribution analysis reflects uncertainty and variability regarding specific parameters (min, max, most likely) typically found within expert surveys (R and Team 2008). An average of the most likely median for each disease was performed to derive individual numbers for application in the DALact (Table 1). PERT distribution was defined by Vose as:

$$\text{Pert}(a,b,c) = \text{Beta}(\alpha_1, \alpha_2) * (c-a) + a$$

Where:

$$\mu = \frac{a + 4 * b + c}{6}$$

$$\alpha_1 = \frac{(\mu - a) * (2b - a - c)}{(b - \mu) * (c - a)}$$

$$\alpha_2 = \frac{\alpha_1 * (c - \mu)}{(\mu - a)}$$

As defined by a = minimum, b = most likely, c = maximum

Individual distributions were combined using a discrete distribution in the form of Discrete ({xi}, {pi}), where {xi} are the expert opinions for experts i = 1 to n and {pi} are the weights given to each expert opinion. Equal weighting was used (Van Hauwermeiren and Vose 2009).

**Table 1: Average Median Disability Weights**

| Disease | Average Median |
| --- | --- |
| Calving Trauma | 0.57 |
| Diarrhea | 0.40 |
| Ketosis | 0.47 |
| Lame (hoof only) | 0.53 |
| Left Displaced Abomasum | 0.60 |
| Mastitis | 0.53 |
| Metritis | 0.47 |
| Milk Fever | 0.53 |
| Musculoskeletal Injury (leg, hip, back) | 0.63 |
| Pneumonia | 0.60 |
| Retained Placenta | 0.37 |
| Right Displaced Abomasum | 0.70 |

Acute disease duration for each disease was also researched as part of a calculation component for the Dairy DALact. As mentioned previously, in order to calculate the Dairy DALact for each disease, prevalence data, duration, and severity scores were necessary. The average duration of disease was applied to all cases on the three dairies in this study (Table 2). For this study averages were estimated based on multiple sources (Hungerford 1990; Divers, Rebhun et al. 2007; Radostits and Done 2007; Kahn, Line et al. 2010). Acute durations of relevant diseases as defined in Rebhun's diseases of dairy cattle for the United States extended from 24 to 96 hours (Divers, Rebhun et al. 2007). Nonetheless, acute duration can be difficult to determine. For example, one study by Warnick et al. found difficulty characterizing clinical lameness on farms and accurately assigning a single duration time; specifically when owner-reported records and non-standardized definitions of lame events are used across farms (Warnick, Janssen et al. 2001). Multiple factors affect the presence, severity, and duration of lameness such as housing and footing type, nutritional subacute ruminal acidosis, and high milk yield (Rajala-Schultz, Gröhn et al. 1999; Cook, Bennett et al. 2004; Stone 2004). Similar to lame conditions, musculoskeletal injuries have been linked to housing facilities, bedding, and cow comfort (Haskell, Rennie et al. 2006; von Keyserlingk, Barrientos et al. 2012). However, clinical definitions and duration vary depending on the injury. Because some musculoskeletal injuries lead to a nonambulatory cow, the duration can be much shorter than 5 days due to euthanasia (Divers, Rebhun et al. 2007; Green, Lombard et al. 2008).

**Table 2: Duration of disease**

| Disease | Duration (d) |
|---|---|
| Calving Trauma | 2 |
| Displaced Abomasum | 3 |
| Diarrhea | 2 |
| Ketosis | 2 |
| Lame | 5 |
| Mastitis | 5 |
| Metritis | 4 |
| Milk Fever | 1 |
| Musculoskeletal Injury | 5 |
| Pneumonia | 4 |
| Retained Placenta | 2 |

*3.3 Results*

Cows on three dairies were enrolled at the time of freshening (calving) from January 1st, 2014 through May 26th, 2015. A total of 2,459 cows were enrolled on Dairy 1. Disease, culled, and died events were continually collected until the end of the project period. Dairy 1 had a total of 160 cows die during the data collection period. This equated to 6.5 cow deaths per 100 enrollments. The death percentage was calculated by taking the total number of dead cows divided by total cows enrolled in the study (160/2,459*100 enrollments) for that dairy.

Dairy 1 reported deaths attributed to the following diseases and conditions: bloat, calving injury, displaced abomasum (DA), diarrhea, down animal (nonambulatory), disease (unspecified), hemorrhagic bowel syndrome, human error, injury (back, hip leg injury that required humane euthanasia), Johnes disease, ketosis, lameness, mastitis, metritis, milk fever, pneumonia, retained placenta, and unknown designation. The highest percentage of deaths were categorized as 'Unknown cause' (28 deaths, 18% of all deaths), followed by left displaced abomasum (22 deaths, 14% of all deaths). Down animals contributed 21 deaths and 13% of all deaths (Table 1). The lowest percentages of deaths were attributed to bloat, human error, and retained placenta; all with 1 death each and 1% or less of all deaths, respectively. A human error death, in this case, refers to a human caused accident that required euthanasia.

Dairy 2 enrolled 2,533 cows during the study period and had a percentage of 5.8 cow deaths per 100 enrollments (147/2,533*100 enrollments). Dairy 2 reported deaths attributed to: calving injury, cancer, displaced abomasum (DA), diarrhea, down animal (nonambulatory), hemorrhagic bowel syndrome, human error, injury, ketosis, lameness, mastitis, metritis, milk fever (MF), pneumonia, retained placenta (RP), and unknown cause(s) (Table 1). Most deaths were attributed to unknown causes (33 deaths, 22%). Of the deaths due to a known disease or injury, injury accounted for the most at 19 cases and 13% of all deaths, followed by calving injury (17, 12%), down (17, 12%) and pneumonia (17, 12%).

Dairy 3 enrolled 2,241 cows in the study. They had 182 dead cows for a percentage of 8.1 cow deaths per 100 enrollments. This dairy reported death due to the following diseases: bloat, bled out (rupture of a major artery), calving injury, displaced abomasum (DA), diarrhea, down animal (nonambulatory), disease (unspecified), hemorrhagic bowel syndrome, human error, injury, Johnes disease, ketosis, lameness, mastitis, metritis, milk fever (MF), pneumonia, retained placenta (RP), septicemia, ulcer and unknown. As with the other 2 dairies, unknown causes accounted for the highest number of deaths with 27 (15% of deaths). The next highest was injury (24, 13%) followed by pneumonia at 21 and 12%, and lastly, down animal (nonambulatory) with 14 deaths and 8% of all deaths (Table 1).

**Table 1: Distribution of diseases attributing to death at all dairies**

| | Dairy 1 | | Dairy 2 | | Dairy 3 | |
|---|---|---|---|---|---|---|
| **Disease** | **Count** | **Percent** | **Count** | **Percent** | **Count** | **Percent** |
| Bled Out | N/A | N/A | N/A | N/A | 2 | 1% |
| Bloat | 1 | 1% | N/A | N/A | 3 | 2% |
| Calving injury | 18 | 11% | 17 | 12% | 9 | 5% |
| Cancer | N/A | N/A | 2 | 1% | N/A | N/A |
| DA | 22 | 14% | 11 | 7% | 11 | 6% |
| Diarrhea | 7 | 4% | 4 | 3% | 11 | 6% |
| Down | 21 | 13% | 17 | 12% | 14 | 8% |
| Disease | 2 | 1% | N/A | N/A | 8 | 4% |
| Hem Bowel | 9 | 6% | 1 | 1% | 3 | 2% |
| Human Error | 1 | 1% | 2 | 1% | 2 | 1% |
| Injury | 16 | 10% | 19 | 13% | 24 | 13% |
| Johnes disease | 2 | 1% | N/A | N/A | 1 | 1% |
| Ketosis | 3 | 2% | 4 | 3% | 4 | 2% |
| Lame | 5 | 3% | 7 | 5% | 10 | 5% |
| Mastitis | 8 | 5% | 5 | 3% | 8 | 4% |
| Metritis | 4 | 3% | 4 | 3% | 10 | 5% |
| MF | 3 | 2% | 2 | 1% | 2 | 1% |
| Pneumonia | 9 | 6% | 17 | 12% | 21 | 12% |
| Septicemia | N/A | N/A | N/A | N/A | 6 | 3% |
| RP | 1 | 1% | 2 | 1% | N/A | N/A |
| Ulcer | N/A | N/A | N/A | N/A | 6 | 3% |
| Unknown | 28 | 18% | 33 | 22% | 27 | 15% |
| **Total** | **160** | **100%** | **147** | **100%** | **182** | **100%** |

Dairy 1 culled 634 cows throughout the study period, representing 25.8% of all enrolled cows. The reasons reported for culling were: abort, “any sickness”, displaced abomasum (DA), diarrhea, disease, injury, Johnes disease, lameness, low production, mastitis, pneumonia, and reproductive. The highest percentage of cows were culled for low production (300 cows and 47% of all culls), followed by “any sickness” (120 animals and 19% of all culls), and lastly, mastitis with 109 cows and 17% of all culls (Table 2).

Dairy 2 sold 590 cows accounting for 23.3% of all enrolled cows. Categories for culling included: abort, “any sickness,” body condition score, displaced abomasum (DA), diarrhea, disease, injury, Johnes disease, “junk,” “kick,” lameness, low production, mastitis, metritis, pneumonia, reproductive and udder. The highest culling category was low production with 319 cows and 54% of all enrolled culled cows. Mastitis was the second highest category with 84 cows leaving the farm, making up 14% of all enrolled culled cows. The third highest category for cull cows was “any sickness” (42, 7%) (Table 2).

Dairy 3 sold 598 cows accounting for 26.6% of all enrolled cows. Categories for culling included: “any sickness,” disease, injury, lameness, low production, mastitis, pneumonia, “record not to be used,” and reproductive. Similar to the other dairies, low production accounted for the largest percentage of removals. This dairy sold 312 enrolled cows for low production, totaling just over half (52%) of all culled cows. Mastitis was the next largest category with 100 cows and 17% of enrolled culled cows. Lameness was the third largest category with 79 cows and 13% (Table 2).

**Table 2: Culling data for all dairies**

| Disease | Dairy 1 | | | Dairy 2 | | | Dairy 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Count | Percent | Avg DIM | Count | Percent | Avg DIM | Count | Percent | Avg DIM |
| Abort | 13 | 2% | 339 | 25 | 4% | 271 | N/A | N/A | N/A |
| Any sickness | 120 | 19% | 121 | 42 | 7% | 180 | 2 | 0% | 289 |
| Body Condition | N/A | N/A | N/A | 1 | 0% | 6 | N/A | N/A | N/A |
| DA | 14 | 2% | 68 | 10 | 2% | 40 | N/A | N/A | N/A |
| Diarrhea | 1 | 0% | 42 | 8 | 1% | 109 | N/A | N/A | N/A |
| Disease | 2 | 0% | 42 | 8 | 1% | 85 | 11 | 2% | 107 |
| Injury | 8 | 1% | 115 | 4 | 1% | 75 | 53 | 9% | 71 |
| Johnes Disease | 1 | 0% | 151 | 4 | 1% | 33 | N/A | N/A | N/A |
| Junk | N/A | N/A | N/A | 11 | 2% | 19 | N/A | N/A | N/A |
| Kick | N/A | N/A | N/A | 3 | 1% | 46 | N/A | N/A | N/A |
| Lame | 25 | 4% | 100 | 22 | 4% | 146 | 79 | 13% | 169 |
| Low Production | 300 | 47% | 196 | 319 | 54% | 140 | 312 | 52% | 202 |
| Mastitis | 109 | 17% | 157 | 84 | 14% | 144 | 100 | 17% | 136 |
| Metritis | N/A | N/A | N/A | 2 | 0% | 22 | N/A | N/A | N/A |
| Pneumonia | 35 | 6% | 94 | 12 | 2% | 128 | 12 | 2% | 158 |
| Record not used | N/A | N/A | N/A | N/A | N/A | N/A | 6 | 1% | 68 |
| Reproductive | 6 | 1% | 341 | 29 | 5% | 341 | 23 | 4% | 336 |
| Udder | N/A | N/A | N/A | 6 | 1% | 10 | N/A | N/A | N/A |
| **Total** | **634** | **100%** | | **590** | **100%** | | **598** | **100%** | |

These data represent the diseases recorded over the entire study period (Tables 3, 4, and 5). It should be mentioned ketosis was not tracked at a level that was reportable at one of the dairies and therefore does not provide a fair comparison.

Dairy 1 had the most abort cases of the three dairies (541 versus 408 versus 210) for Dairies 1, 2, and 3, respectively. Lameness accounted for only 17% of cases at Dairy 1, while Dairies 2 and 3 had 35% of cases due to lameness. Dairy 2 had the lowest number of cases of mastitis (783, 23%) versus Dairy 1 and 3 (1,160 and 33% and 1,025 and 30%), respectively.

**Table 3: Disease prevalence at Dairy 1**

| Disease | Cases | Cows with 2 or more events | Total cows with event | % of cases | % of cows* |
|---|---|---|---|---|---|
| Abort | 541 | 55 | 489 | 15% | 20% |
| Bloat | 4 | 0 | 4 | 0% | 0% |
| DA | 100 | 0 | 100 | 3% | 4% |
| Diarrhea | 67 | 2 | 65 | 2% | 3% |
| Down | 38 | 0 | 38 | 1% | 2% |
| Ketosis | 128 | 0 | 128 | 4% | 5% |
| Lame | 614 | 102 | 481 | 17% | 20% |
| Mastitis | 1160 | 242 | 821 | 33% | 33% |
| Metritis | 483 | 12 | 471 | 14% | 19% |
| MF | 50 | 0 | 50 | 1% | 2% |
| Pneumonia | 166 | 0 | 166 | 5% | 7% |
| RP | 194 | 0 | 194 | 5% | 8% |
| **Total Cases** | **3545** | | | | |

*Based on 2,459 total cows enrolled in the study

**Table 4: Disease prevalence at Dairy 2**

| Disease | Cases | Cows with 2 or more events | Total cows with event | % of cases | % of cows* |
|---|---|---|---|---|---|
| Abort | 408 | 37 | 371 | 12% | 15% |
| Bloat | 3 | 0 | 3 | 0% | 0% |
| DA | 66 | 0 | 66 | 2% | 3% |
| Diarrhea | 136 | 14 | 122 | 4% | 5% |
| Down | 27 | 0 | 27 | 1% | 1% |
| Ketosis | 107 | 0 | 107 | 3% | 4% |
| Lame | 1210 | 254 | 836 | 35% | 33% |
| Mastitis | 783 | 148 | 588 | 23% | 23% |
| Metritis | 338 | 10 | 328 | 10% | 13% |
| MF | 22 | 0 | 22 | 1% | 1% |
| Pneumonia | 125 | 0 | 125 | 4% | 5% |
| RP | 215 | 0 | 215 | 6% | 8% |
| **Total Cases** | **3440** | | | | |

*Based on 2,533 total cows enrolled in the study

**Table 5: Disease prevalence at Dairy 3**

| Disease | Cases | Cows with 2 or more events | Total cows with event | % of cases | % of cows* |
|---|---|---|---|---|---|
| Abort | 210 | 9 | 200 | 6% | 9% |
| Bloat | 1 | 0 | 1 | 0% | 0% |
| DA | 94 | 0 | 94 | 3% | 4% |
| Diarrhea | 45 | 0 | 45 | 1% | 2% |
| Down | 39 | 0 | 39 | 1% | 2% |
| Ketosis | 7 | 0 | 7 | 0% | 0% |
| Lame | 1178 | 251 | 784 | 35% | 35% |
| Mastitis | 1025 | 237 | 674 | 30% | 30% |
| Metritis | 421 | 42 | 379 | 13% | 17% |
| MF | 40 | 0 | 40 | 1% | 2% |
| Pneumonia | 63 | 0 | 63 | 2% | 3% |
| RP | 239 | 3 | 236 | 7% | 11% |
| **Total Cases** | **3362** | | | | |

*Based on 2,241 total cows enrolled in the study

Dairy 1 had 740 cows that completed a lactation throughout the 17-month study period. Of those cows, 445 cows had disease events and the remaining 295 cows had no disease events. Dairy 1 had a total of 493 disease cases with 4 categories having repeat cases. Lameness and mastitis had the highest percentage of cases. The highest percentage of disease events were attributed to mastitis with 44% of cases followed by 26% of all cases in the lameness category (Table 6).

**Table 6: Completed lactation disease prevalence for Dairy 1**

| Disease | Cases | Cows with 2 or more cases | % of cases | Avg DIM |
|---|---|---|---|---|
| Abort | 46 | 4 | 9% | 135 |
| DA | 7 | 0 | 1% | 14 |
| Diarrhea | 7 | 0 | 1% | 79 |
| Down | 2 | 0 | 0% | 1 |
| Lame | 126 | 49 | 26% | 170 |
| Mastitis | 215 | 110 | 44% | 174 |
| Metritis | 60 | 6 | 12% | 7 |
| MF | 4 | 0 | 1% | 1 |
| Pneumonia | 19 | 0 | 4% | 96 |
| RP | 7 | 0 | 1% | 4 |
| **Total** | **493** | **169** | **100%** | |

Dairy 2 had a total of 398 cows with completed lactations. Of those cows, 223 had completed lactations with disease events and 175 cows had zero disease events. Dairy 2 had a total of 357 disease cases with 3 categories having repeat cases. According to these data, lameness makes up almost half (49%) of all cases followed by mastitis at 27% (Table 7). Average days in milk of diseases seem to follow appropriate biological time frames for early lactation and later lactation diseases to typically occur.

**Table 7: Completed lactation disease prevalence for Dairy 2**

| Disease | Cases | Cows with 2 or more cases | % of cases | Avg DIM |
|---|---|---|---|---|
| Abort | 22 | 0 | 6% | 136 |
| DA | 3 | 0 | 1% | 15 |
| Diarrhea | 8 | 0 | 2% | 65 |
| Down | 2 | 0 | 1% | 214 |
| Lame | 175 | 40 | 49% | 173 |
| Mastitis | 98 | 23 | 27% | 173 |
| Metritis | 24 | 0 | 7% | 8 |
| MF | 4 | 0 | 1% | 2 |
| Pneumonia | 9 | 1 | 3% | 118 |
| RP | 12 | 0 | 3% | 2 |
| **Total** | **357** | **64** | **100%** | |

Dairy 3 had a total of 401 cows with completed lactations. Of those cows, 236 cows had completed lactations with disease events and 165 had zero disease events. Dairy 3 had a total of 464 disease cases. Mastitis events were first with 39% of cases, followed by lameness at 34% and lastly by retained placenta and metritis (Table 8).

**Table 8: Completed lactation disease prevalence for Dairy 3**

| Disease | Cases | Cows with 2 or more cases | % of cases | Avg DIM |
|---|---|---|---|---|
| Abort | 6 | 0 | 1% | 152 |
| DA | 10 | 0 | 2% | 20 |
| Diarrhea | 4 | 0 | 1% | 29 |
| Down | 7 | 0 | 2% | 84 |
| Lame | 158 | 53 | 34% | 167 |
| Mastitis | 180 | 68 | 39% | 97 |
| Metritis | 38 | 0 | 8% | 10 |
| MF | 7 | 0 | 2% | 1 |
| Pneumonia | 10 | 0 | 2% | 31 |
| RP | 44 | 0 | 9% | 2 |
| **Total** | **464** | **121** | **100%** | |

*3.4 DALact Calculation (Disease Adjusted Lactation)*

The DALact metric was calculated in two parts. The first part calculated the time lost to deaths or culling from a given disease using the percentage of cows that died or were culled and multiplying it by the dairy's calving interval in days minus the average days in milk at the time of death or removal. The second portion calculates the time lost to a given disease by multiplying the appropriate disability weight by the duration, disease prevalence, and total cows enrolled in the study. For example, displaced abomasum (DA) DALact death/culling calculation for Dairy 1 follows: (160*0.14)*(390-43)+(634*0.022)*(390-68)=12,142 days lost. DA DALact disease calculation for Dairy 1 follows: 0.60*3*0.03*2,459=133 days lost. The two numbers were added together for the total time lost to that disease on the dairy (12,275 days).

Table 9 reports death and culling categories, average days in milk at removal, disability weights, and disease duration for Dairy 1. DALact calculations for dead and culled cows, disease, and total value are also reported. The category with greatest time lost was attributed to mastitis with 29,779 days. Pneumonia had the next greatest time lost (13,571 days) followed by displaced abomasum (12,275 days).

**Table 9: Death, culling, and disease DALact calculation for Dairy 1**

| Disease | Count (dead) | Avg DIM at death | DALact days (dead) | Count (cull) | Avg DIM at cull | DALact days (cull) | Disability Weight | Duration (days) | Prevalence cases^ | DALact Disease~ | Total DALact (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Calving injury | 18 | 4 | 6,948 | N/A | N/A | N/A | 0.57 | 2 | N/A | N/A | 6,948 |
| DA | 22 | 43 | 7,634 | 14 | 68 | 4,508 | 0.60 | 3 | 3% | 133 | 12,275 |
| Diarrhea | 7 | 60 | 2,310 | 1 | 42 | 348 | 0.40 | 2 | 2% | 39 | 2,697 |
| Musculoskeletal Injury | 16 | 78 | 4,992 | 8 | 115 | 2,200 | 0.63 | 5 | N/A | N/A | 7,192 |
| Ketosis | 3 | 17 | 1,119 | N/A | N/A | N/A | 0.47 | 2 | 4% | 92 | 1,211 |
| Lame | 5 | 39 | 1,755 | 25 | 100 | 7,250 | 0.53 | 5 | 17% | 1108 | 10,113 |
| Mastitis | 8 | 111 | 2,232 | 109 | 157 | 25,397 | 0.53 | 5 | 33% | 2150 | 29,779 |
| Metritis | 4 | 13 | 1,508 | N/A | N/A | N/A | 0.47 | 4 | 13% | 601 | 2,109 |
| MF | 3 | 8 | 1,146 | N/A | N/A | N/A | 0.53 | 1 | 1% | 8 | 1,154 |
| Pneumonia | 9 | 66 | 2,916 | 35 | 94 | 10,360 | 0.60 | 4 | 5% | 295 | 13,571 |
| RP | 1 | 4 | 386 | N/A | N/A | N/A | 0.37 | 2 | 5% | 91 | 477 |
| Other*ꜝ | 64 | N/A | N/A | 442 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **Total** | **160** | | | **634** | | | | | | | |

6.5 deaths per 100 cow lactations

^Based on 3,545 total event cases throughout study

~Based on 2,459 total enrolled cows for study

*Other deaths not calculated in DALact include bloat, down, disease, hemorrhagic bowel, human error, Johnes disease, and unknown

ꜝ Other culls not calculated in DALact include abort, any sickness, disease, Johnes disease, low production, and reproductive

Table 10 reports death and culling according to assigned disease, average days in milk at removal, disability weights, and disease duration for Dairy 2. Also reported is the DALact calculation for dead and culled cows as well as for disease and the total DALact value for each disease. The highest DALact for any disease was 23,917 days lost due to mastitis. The total value included 1,725 days lost to death, 20,664 days lost to culling, and 1,528 days lost due to disease. The next disease with greatest time lost was lameness with a total of 9,934 days lost. Pneumonia had the third greatest time lost with 8,720 days lost.

**Table 10: Death, culling, and disease DALact calculation for Dairy 2**

| Disease | Count (dead) | Avg DIM at death | DALact days (dead) | Count (cull) | Avg DIM at Cull | DALact days (cull) | Disability Weight | Duration (days) | Prevalence cases^ | DALact Disease~ | Total DALact (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Calving injury | 17 | 2 | 6,596 | N/A | N/A | N/A | 0.57 | 2 | N/A | N/A | 6,596 |
| DA | 11 | 25 | 4,015 | 10 | 40 | 3,500 | 0.60 | 3 | 2% | 87 | 7,602 |
| Diarrhea | 4 | 112 | 1,112 | 8 | 109 | 2,248 | 0.40 | 2 | 4% | 80 | 3,440 |
| Musculoskeletal Injury | 19 | 120 | 5,130 | 4 | 75 | 1,260 | 0.63 | 5 | N/A | N/A | 6,390 |
| Ketosis | 4 | 18 | 1,488 | N/A | N/A | N/A | 0.47 | 2 | 3% | 74 | 1,562 |
| Lame | 7 | 75 | 2,205 | 22 | 146 | 5,368 | 0.53 | 5 | 35% | 2,361 | 9,934 |
| Mastitis | 5 | 45 | 1,725 | 84 | 144 | 20,664 | 0.53 | 5 | 23% | 1,528 | 23,917 |
| Metritis | 4 | 10 | 1,520 | 2 | 22 | 736 | 0.47 | 4 | 10% | 468 | 2,724 |
| MF | 2 | 3 | 774 | N/A | N/A | N/A | 0.53 | 1 | 1% | 9 | 783 |
| Pneumonia | 17 | 75 | 5,355 | 12 | 128 | 3,144 | 0.60 | 4 | 4% | 221 | 8,720 |
| RP | 2 | 3 | 774 | N/A | N/A | N/A | 0.37 | 2 | 6% | 117 | 891 |
| Other*ᶧ | 55 | N/A | N/A | 448 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **Total** | **147** | | | **590** | | | | | | | |

5.8 deaths per 100 cow lactations

^Based on 3,440 total event cases throughout study

~Based on 2,533 total enrolled cows for study

*Other deaths not calculated in DALact include cancer, down, hemorrhagic bowel, human error, and unknown

ᶧ Other culls not calculated in DALact include abort, any sickness, body condition, disease, Johnes disease, junk, kick, low production, reproductive,
ᶧ udder and unknown

Table 11 reports death and culling according to assigned disease, average days in milk at removal, disability weights, and duration for each disease for Dairy 3. DALact calculations for death, culling, and disease are also included. Mastitis was found to have the greatest time lost at 36,183 days. The next category with greatest time lost was lameness with 29,912 days.

## Table 11: Death, culling, and disease DALact calculation for Dairy 3

| Disease | Count (dead) | Avg DIM at death | DALact days (dead) | Count (cull) | Avg DIM at cull | DALact days (cull) | Disability Weight | Duration (days) | Prevalence cases^ | DALact Disease~ | Total DALact (days) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Calving injury | 9 | 2 | 3,492 | N/A | N/A | N/A | 0.57 | 2 | N/A | N/A | 3,492 |
| DA | 11 | 19 | 4,081 | N/A | N/A | N/A | 0.60 | 3 | 3% | 113 | 4,194 |
| Diarrhea | 11 | 81 | 3,399 | N/A | N/A | N/A | 0.40 | 2 | 1% | 24 | 3,423 |
| Musculoskeletal Injury | 24 | 87 | 7,272 | 53 | 71 | 16,907 | 0.63 | 5 | N/A | N/A | 24,179 |
| Ketosis | 4 | 10 | 1,520 | N/A | N/A | N/A | 0.47 | 2 | 0% | 4 | 1,524 |
| Lame | 10 | 127 | 2,630 | 79 | 169 | 25,201 | 0.53 | 5 | 35% | 2,081 | 29,912 |
| Mastitis | 8 | 81 | 2,472 | 100 | 136 | 31,900 | 0.53 | 5 | 30% | 1,811 | 36,183 |
| Metritis | 10 | 19 | 3,710 | N/A | N/A | N/A | 0.47 | 4 | 13% | 528 | 4,238 |
| MF | 2 | 5 | 770 | N/A | N/A | N/A | 0.53 | 1 | 1% | 14 | 784 |
| Pneumonia | 21 | 102 | 6,048 | 12 | 158 | 3,828 | 0.60 | 4 | 2% | 101 | 9,977 |
| RP | 0 | N/A | 0 | N/A | N/A | N/A | 0.37 | 2 | 7% | 117 | 117 |
| Other* ᴵ | 72 | N/A | N/A | 354 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| **Total** | **182** | | | **598** | | | | | | | |

8.1 deaths per 100 cow lactations

^Based on 3,362 total event cases throughout study

~Based on 2,241 total enrolled cows for study

*Other deaths not calculated in DALact include bled out, bloat, down, disease, hemorrhagic bowel, human error, Johnes disease, septicemia,

*ulcer, and unknown

ᴵ Other culls not calculated in DALact include any sickness, disease, low production, record not to be used, and reproduction

*3.5 Discussion*

The decision to cull dairy cows is one that differs farm-by-farm as well as by individual animal. The two main reasons for culling are biologic and economic and they are not always easy to distinguish. Some cows are culled due to low milk production and others for biological reasons. The criteria that are used to determine if an animal should be culled for economic reasons often doesn't follow a specific process and is mostly influenced by the perception of the manager or owner at the time of the decision (Lehenbauer and Oltjen 1998). Biologic issues are another reason for an animal to be culled from the herd. These can manifest as lameness, mastitis, chronic, repeated illness, or other incurable disease states. Usually this is also based partially on the intuition of the herd manager.

The three farms that participated in this study are all owned and operated with the intent of managing them similarly. The biggest category for all three dairies culling data was low production, which is an economic decision. The three dairies use the same criteria for culling an animal with low milk production, assuming there are replacement animals for each farm. Dairy 1 culled 634 animals throughout the study period and 47% of those left because of low milk production. The second biggest contributor was "any sickness" (19%) followed by mastitis (17%). Dairy 2 culled 590 animals, where 54% left due to low milk production followed by 14% for mastitis. Dairy 3 culled 598 animals with 50% leaving due to low milk production followed by mastitis (17%). It is not surprising, however, that the percentage of low production animals leaving the farms varied. The final decision was made by a different person at each farm, even if there was a specific break-even point for milk. Underlying information regarding the reasons for leaving were difficult to determine based on the current single code system used on many dairies. According to a 1996 NAHMS dairy report, the main reasons for culling an animal were udder/mastitis, reproductive problems, poor production, and lameness (Centers for Epidemiology and Animal Health 1996). Based on this information, the apparent reasons for culling on the participating farms seem to be similar to the rest of the country. However, in order to understand more about animals that are removed, more information would need to be included in culling codes.

Dairy cow morbidity is often recorded in various ways on farms. Herd management software is used on many dairies to better track prevalence of diseases on the farm to find places of focus and improvement. As transparency on farms is increasingly becoming an issue to the public and farmer, improved methods of recording and analyzing disease data should be an integral part of management. Tracking disease prevalence in this project was essential to calculating the DALact. Up-to-date and accurate records of disease occurrences are a crucial part of calculating the time lost due to a given disease. Using the farm's disease prevalence numbers customizes the time lost for that farm. When combined with disability weights and duration, it gives an additional picture of the disease and death issues on the farm.

Dairy 1 had 3,545 health events throughout the study period. Of those events, mastitis was the most frequent at 33% of all cases, followed by lameness (17%) and then abortions (15%). When cows that had full lactations were analyzed, the results were similar with the exception of the third highest disease. Mastitis was still the most common disease, followed by lameness, then metritis.

These disease prevalence numbers were used to calculate the DALact. Based on disease DALact numbers alone, mastitis caused the most time lost (2,150 days), followed by lameness (1,108 days) and then metritis (601 days). The total DALact for mastitis came to 29,779 days lost. The next highest loss of time was attributed to pneumonia with 13,571 days lost. Displaced abomasum accounted for the third highest loss of time with 12,275 days lost. Musculoskeletal injury deaths made up 10% of cows that died on the farm. This event, unfortunately, was not recorded as a disease (i.e. it only served as a culling or death category) and is an area that should be addressed in managerial efforts to reduce the number of deaths due to injuries. In addition, the disability weight for this event is the greatest, indicating that many people agree that it can be a fairly severe injury and lead to death. This high disability weight in combination with a long disease duration and high prevalence suggests injuries should be considered in future management discussions.

Dairy 2 totaled 3,440 disease events throughout the study period. This dairy had lameness as a bigger problem than mastitis. 35% of all cases were lameness cases compared to 23% for mastitis. Abortions came in third at 12%. Full lactation data showed similar results. Lameness was almost 50% of all cases in full lactation cows, followed by mastitis and then by metritis. Abortions were lower in the full lactation data for the same reason as for Dairy 1.

When combined into the DALact calculation, mastitis accounted for the greatest time lost with 23,917 days lost followed by lameness (9,934 days lost) and pneumonia (8,720 days). Most of mastitis days lost can be attributed to the number of cows that were culled due to the disease. 84 cows were culled equating to 20,664 days lost. Pneumonia had the most days lost due to deaths (5,355). Pneumonia should be involved in future health discussions because it was the second highest days lost for deaths behind calving injury (6,596 days lost).

Dairy 3 had 3,362 disease events throughout the study. The disease category with the most cases was attributed to lameness (35%) followed by mastitis (30%) and lastly metritis (13%). When calculated in the DALact, Dairy 3 had mastitis as the disease with the most days lost (36,183 days) followed by lameness (29,912 days lost) and finally by musculoskeletal injury

(24,179 days lost). At this dairy, injury was the third highest days lost category due to the high number of cows culled due to injury (16,907).

The goal of this methodology is to provide a different way at looking at the problems that arise on a farm other than simply taking monthly incidence or prevalence data. Highlighting certain problem areas in health, removal, and death data would provide the farm with a new layer of insight into increased animal welfare awareness and potential farm management adjustments. The hope is that this measure would lead to overall increased health of dairy herds which in turn has the potential to increase farm productivity and efficiency. Better records, necropsies, and systematic, specific information will provide the feedback that is desired by the farm; however, that cannot be the full scenario when information is missing.

# CHAPTER 4: DISCUSSION OF DALACT METRIC

The World Health Organization developed the disability-adjusted life year (DALY) to quantify the current impacts, future risks, and burden of human morbidity and mortality at a global level in order to assist in public health prioritization (Murray and Acharya 1997). Comprised of healthy years lost to death and disease, the DALY aims to treat “like health outcomes as like” in order to incorporate a balanced and comparable measure into cost-effective public health policy focused on well-being that is useful within regions and across the globe (Murray 1994). The DALY methodology used in recent research spans multiple disciplines and has been coupled with predictive models for benchmarking and reporting, assisted in assessments of current cost-effectiveness of public health interventions, and even provided the framework for estimating the burden of disease for a given food additive (Valencia-Mendoza, Danese-dlSantos et al. 2011; Veeramany and Mangalam 2014; Jakobsen, Granby et al. 2016).

Many health measures use incidence and prevalence rates to describe the presence of diseases and death that are often specific to a particular entity. An example is a study that examined the use of DALY methodology on health impacts of microbial infection risks in water reuse systems. That study highlighted that traditional measures use infection rates calculated by a beta-Poisson or exponential model which do not account for different population characteristics, severity, duration, or after-infection total health loss (Gao, Chen et al. 2016). The DALY specifically incorporates the severity of a disease into the DALY calculation through the use of disability weights and standardized duration times for diseases to provide a more comprehensive assessment of the effects of given diseases and injuries.

The human DALY attempts to incorporate cost-effectiveness and well-being into a single health loss measure by quantifying premature death and combining those data with nonfatal health outcomes and injuries (Gold, Stevenson et al. 2002). These principles were the inspiration behind developing such a metric for dairy cow morbidity and mortality. Increasing levels of dairy cow mortality and morbidity have been recorded in the last couple of decades and are inherently linked to animal welfare and farm-level economic concerns (Thomsen, Dahl-Pedersen et al. 2012; Alvåsen, Jansson Mörk et al. 2014; Trevisi, Zecconi et al. 2014; McConnel, Lombard et al. 2015). Couple the aforementioned with increased public concern regarding antibiotic use and residues and there is a sound argument for developing novel ways to assess and mitigate dairy cow death and disease. (Trevisi, Zecconi et al. 2014; Ventura, von Keyserlingk et al. 2015).

In order to adapt the DALY metric for potential application to dairy farm records, a few components needed to be developed. The first being the derivation of disability weights of diseases through a survey of experts in the dairy industry. An expert was defined as a farm manager, producer, or veterinarian with experience in dairy cow health and management. Experts were asked to assess the impact on an animal's health and production of 12 common dairy cow diseases from 0 (healthy) to 10 (dead) using a minimum, maximum, and most likely ranking. These results were analyzed using a Pert distribution to establish a median most likely value that was used in the disease-adjusted lactation yield (DALact) calculation as a disease's assigned disability weight (Van Hauwermeiren and Vose 2009).

Two other important components of the DALact are standardized acute durations of diseases and on-farm prevalence of those diseases. Acute durations for 12 diseases were researched in veterinary medicine textbooks and journal articles (Hungerford 1990; Warnick, Janssen et al. 2001; Divers, Rebhun et al. 2007; Radostits and Done 2007; Kahn, Line et al.

2010). On-farm prevalence data were obtained from 3 Kansas-based dairies that were owned and operated by a single family but in separate locales. For a period of 17 months, cows that freshened were enrolled and health events, deaths, and culls of those cows were tracked until the end of the study. Individual cow health, death, and culling records were imported from herd management software (Dairy Comp 305, Valley Agricultural Software, 2016) into Microsoft Excel (2010) and organized based on outcome: present on-farm with disease events, present on-farm without disease events, died on-farm, or sold. Mortality, morbidity and culling data were combined with disability weights and acute durations of disease to calculate a total DALact value for days lost due to a given disease.

Much like the human DALY, the use of this metric is not without drawbacks. The DALY metric's critics have issues with ethical implications, lack of supporting prevalence data in some areas of the globe, and reliability of mortality records (Anand and Hanson 1997; Cooper, Osotimehin et al. 1998). While not all of the human DALY's concerns are shared with the dairy DALact, there are a few components of the DALact that need to be addressed in the dairy industry as a whole and shifting a paradigm is not easily achievable. The industry should work towards improving cow removal records and morbidity data in order to gain more information that allows farmers to be proactive as opposed to reactive. In order to gain useful information via the DALact, records need to provide an accurate representation of farms' disease and removals (culling and death).

One of the areas for the DALact to investigate in the future may be measuring the follow-on effects of diseases (sequelae) and chronic states from calf-hood to adulthood. The DALY incorporates a set of escalating classes describing the loss of welfare/severity of disease into disability weights (Murray 1994). As the severity gets worse, the class for that disease increases along with the disability weight. Future considerations for the DALact could involve deriving classes that assess levels of severity or sickness in calves that are combined with disease-specific disability weights in adult cattle. Accounting for reduced health in calves that could carry on into adulthood might assist in management of individual animals once they enter the herd as lactating cows.

Similar to the DALY's multifactorial use across disciplines, specifically in cost-effective analyses, the DALact may provide dairies with another level of economic strategy in the future. Oostvogels et al. suggests that the purpose of the DALY in cost-effective analyses is to provide comparability and to combine time lost with cost (Oostvogels, De-Wit et al. 2015). Assigning costs to diseases and injuries can provide the framework for resource allocation in the future, evaluate current interventions, and provide the basis for standard procedures and strategies (Rice 2000). Costs can be direct or indirect. Direct costs are tangible such as medicine and indirect costs are less tangible such as missed days of productive work.

The same costs can apply at a dairy farm. Direct costs involved with a disease process in a dairy cow include price of medicine, cost of labor, lowered milk production. Post-disease effects such as reproduction issues and lower peak milk, as well as sequelae are all indirect costs and less tangible. Galligan argues that, for dairy producers to be sustainable in the future, overall herd performance and management must operate at an optimum level. Running an operation in any less than optimal state is economic opportunity lost and could greatly cost the business (Galligan 2006). The DALact in the future may perhaps be combined with the direct, indirect, opportunity and dollar costs on dairies to provide a more comprehensive measure of all costs, welfare implications, future possibilities and time lost due to suboptimal health states on a farm.

If the dairy industry continues to be pressured to become more transparent, changes with heath and mortality recording will need to occur. Animal welfare will remain a concern for the public and industry members alike, as will cost effective strategies that address different management techniques (Ventura, von Keyserlingk et al. 2015). The DALact measure will be an ongoing project, similar to the DALY, which will add value to dairy producer's management, animal welfare, and economic strategies.

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# APPENDIX A

# EXPERT OPINION SURVEY

## Part 1: Background Information

**Please write your title (Producer, Manager, Veterinarian):**________________________________

**Primary state and country of operation/practice:**

_______________________________________

*If producer/manager, please write number of milking cows*:

_______________________________

**Years in operation/practice**:

________________________________________________________

## Part 2: Severity of Disease

**2.1. On a scale of 1-10, please rank the severity of the following diseases in terms of their impact on dairy cow health and milk production. Rank a *minimum*, *maximum*, and *most likely* impact for each disease based on your experience with individual cows in your herd.**

**For example, Pinkeye cases may *minimally* cause mild irritation and no drop in milk production. This might be ranked a one (1). *Maximally*, Pinkeye may lead to removal of the eye, a significant impact on milk production, but not euthanasia or death. This might be ranked a four (4).The *most likely* outcomes of Pinkeye are corneal scarring and an insignificant impact on milk production. This might be ranked a two (2). In some cases, *most likely* could be equal to *minimum* or *maximum*.**

| Disease | Least Impact | | | | | | | | Euthanasia or Death |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Pink Eye | X | X | | X | | | | | | |
| Calving Trauma | | | | | | | | | | |
| Diarrhea | | | | | | | | | | |
| Ketosis | | | | | | | | | | |
| Lame (hoof only) | | | | | | | | | | |
| Left Displaced Abomasum | | | | | | | | | | |
| Mastitis | | | | | | | | | | |
| Milk Fever | | | | | | | | | | |
| Metritis | | | | | | | | | | |
| Musculoskeletal injury (leg, hip, back) | | | | | | | | | | |
| Pneumonia | | | | | | | | | | |
| Retained Placenta | | | | | | | | | | |
| Right Displaced Abomasum | | | | | | | | | | |

## Part 3: Likelihood of Culling

**Please classify the likelihood of culling an animal with a specific disease *<u>because</u>* of that disease using a *minimum*, *maximum*, and *most likely* ranking.**

**For example, Johne's Disease may lead to different culling outcomes dependent upon the disease severity and dairy management goals. A *minimum* of 20% and a *maximum* of 100% of Johne's positive cows might be culled because of the disease. However, the *most likely* outcome might be that 60% of Johne's positive cows are culled because of Johne's.**

**3.1.** For the following table, consider cows ***less than 60 days in milk and <u>not pregnant</u>.*** Again, in some cases *most likely* could be equal to *minimum* or *maximum*. If you have no experience with a disease, please use N/A, not applicable.

| Disease | N/A | 10% | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Johne's Disease | | | X | | | | X | | | | X |
| Calving Trauma | | | | | | | | | | | |
| Diarrhea | | | | | | | | | | | |
| Ketosis | | | | | | | | | | | |
| Lame (hoof only) | | | | | | | | | | | |
| Left Displaced Abomasum | | | | | | | | | | | |
| Mastitis (contagious) | | | | | | | | | | | |
| Mastitis (environmental) | | | | | | | | | | | |
| Milk Fever | | | | | | | | | | | |
| Metritis | | | | | | | | | | | |
| Musculoskeletal Injury (leg, hip, back) | | | | | | | | | | | |
| Pneumonia | | | | | | | | | | | |
| Pyometra | | | | | | | | | | | |
| Right Displaced Abomasum | | | | | | | | | | | |

**3.2.** ***60-200 days in milk and <u>not pregnant</u>***

| Disease | N/A | 10% | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diarrhea | | | | | | | | | | | |
| Lame (hoof only) | | | | | | | | | | | |
| Left Displaced Abomasum | | | | | | | | | | | |
| Mastitis (contagious) | | | | | | | | | | | |
| Mastitis (environmental) | | | | | | | | | | | |
| Musculoskeletal Injury (leg, hip, back) | | | | | | | | | | | |
| Pneumonia | | | | | | | | | | | |
| Pyometra | | | | | | | | | | | |
| Right Displaced Abomasum | | | | | | | | | | | |

## Part 3 Continued:

**3.3.** ***60-200 days in milk and <u>pregnant</u>***

| Disease | N/A | 10% | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Abortion (during this lactation) | | | | | | | | | | | |
| Diarrhea | | | | | | | | | | | |
| Lame (hoof only) | | | | | | | | | | | |
| Left Displaced Abomasum | | | | | | | | | | | |
| Mastitis (contagious) | | | | | | | | | | | |
| Mastitis (environmental) | | | | | | | | | | | |
| Musculoskeletal Injury (leg, hip, back) | | | | | | | | | | | |
| Pneumonia | | | | | | | | | | | |
| Right Displaced Abomasum | | | | | | | | | | | |

**3.4.** **G*reater than 200 days in milk and <u>not pregnant</u>***

| Disease | N/A | 10% | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Diarrhea | | | | | | | | | | | |
| Lame (hoof only) | | | | | | | | | | | |
| Mastitis (contagious) | | | | | | | | | | | |
| Mastitis (environmental) | | | | | | | | | | | |
| Musculoskeletal Injury (leg, hip, back) | | | | | | | | | | | |
| Pneumonia | | | | | | | | | | | |
| Pyometra | | | | | | | | | | | |

**3.5.** **G*reater than 200 days in milk and <u>pregnant</u>***

| Disease | N/A | 10% | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100% |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Abortion (during this lactation) | | | | | | | | | | | |
| Diarrhea | | | | | | | | | | | |
| Lame (hoof only) | | | | | | | | | | | |
| Mastitis (contagious) | | | | | | | | | | | |
| Mastitis (environmental) | | | | | | | | | | | |
| Musculoskeletal Injury (leg, hip, back) | | | | | | | | | | | |
| Pneumonia | | | | | | | | | | | |

## Part 4: Cost of Disease

**4.1. Please rank the top five (5) most expensive diseases on a dairy. Use a 1-5 scale, where a score of one (1) is the least costly disease and a score of five (5) is the most costly. Each number should appear only once. For the purpose of this question, please consider expenses consisting only of labor, treatment costs, and milk production lost.**

| Disease | 1-5 |
|---|---|
| Abortion | |
| Calving Trauma | |
| Diarrhea | |
| Ketosis | |
| Lame (hoof only) | |
| Left Displaced Abomasum | |
| Mastitis | |
| Milk Fever | |
| Metritis | |
| Musculoskeletal injury (leg, hip, back) | |
| Pneumonia | |
| Retained Placenta | |
| Right Displaced Abomasum | |

**Thank you. Your time and input is greatly appreciated.**

**Please send questions and comments to Dr. Craig McConnel, DVM (craig.mcconnel@colostate.edu) and Ashleigh McNeil (aamcneil@rams.colostate.edu).**