HERD VARIABLES ASSOCIATED WITH MILKING EFFICIENCY OF DAIRY CATTLE

By

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A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Comparative Medicine and Integrative Biology – Doctor of Philosophy

2018

ABSTRACT

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Over the past two decades, there has been a marked shift in herd size distribution among dairy farms in the U.S.; farms with fewer than 100 cows accounted for 49% of the country's milk cows in 1992, but just 17% of milk cows in 2012. In contrast, farms with at least 1,000 cows accounted for 49% of all milk cows in 2012, an increase from 10% in 1992. As overall herd size increases, dairy farms are also becoming more reliant on the hiring of non-family labor. However, greater reliance on employees has raised new challenges for training and compliance of critical farm protocols, including milking cows. Improper milking can impact the health of dairy cattle, particularly with respect to mastitis. Bovine mastitis is one of the most important diseases of dairy cattle in the United States and continues to cause major economic losses to the dairy industry, due to decreased farm productivity and quality of dairy foods. Crucially, the capacity of farms to train and educate personnel may play a key role in mastitis control and milking efficiency. However, many farms have not adapted management strategies to address changes in the employee training and education landscape. This 'cultural lag' in the dairy industry has warranted further study of the labor culture on dairy farms, and to find the means to assess employee performance and success of employee training, as measured by the milking efficiency.

Therefore, the hypothesis of Chapter 2 was that employee and management factors affect milking efficiency of cows as measured by the proportion of cows within a herd with delayed milk ejection. Results of this study showed that herd size and mean stimulation time during pre-

milking preparation was a significant factor in the proportion of cows with delayed milk ejection. While past research indicates that stimulation time is important for proper milk ejection, it is a novel concept that stimulation time has the possibility of overriding many other factors that may play a role. However, this did not fully explain the employee factors that could potentially affect milking efficiency. To further investigate this relationship, Chapter 3 hypothesized that employee and management factors had an effect on the mean stimulation time during the pre-milking protocol. The results of that study showed that increasing lag time during the pre-milking routine was positively associated with increasing mean stimulation time. However, herd size and the number of passes during the pre-milking routine was negatively associated with mean stimulation time. These results suggest that employees who were expected to complete more tasks in a shorter amount of time were less likely to properly stimulate teats before milking, which as determined in Chapter 2, then leads to greater frequency of delayed milk ejection.

In addition to delayed milk ejection, overmilking of cows (the time period when milking units are attached to teats with no milk flowing) is a critical measure of milking efficiency. Overmilking not only increases the amount of time that cows are unable to rest and eat, but also exposes teats to high vacuum levels and subsequently, increases the risk of mastitis. Chapter 4 hypothesized that there were employee and management factors that are associated with median overmilking time in a herd. The results of this study found that herds with a shorter duration of daily milking periods had a greater proportion of overmilked cows. These results suggested that farm owners or operators who milk cows on farms that do not attain the full daily capacity of the milking equipment, may be making subjective decisions to milk cows inefficiently from overmilking.

This dissertation is dedicated to my family, especially my parents, Chuck and Terri Moore. Most importantly also to my husband, Erik Foster. Who have all supported me unconditionally throughout this journey.

Thank you for everything, I could not have done it without you.

ACKNOWLEDGEMENTS

A special thanks to:

- My mentor and major advisor, Dr. Ronald J. Erskine, for all of the guidance, mentorship and life advice. I appreciate your encouragement and support through this entire process.
- Dr. Paul Bartlett, for the mentorship in statistics.
- Dr. Bo Norby, for the mentorship in SAS and statistics.
- Dr. Rebecca Schewe, for the mentorship in rural sociology and survey design.
- Dr. Roger Thomson, for the mentorship in milking machine systems and parlor evaluations.
- Trevor Lloyd-James, Caitlin McNichols, Leah Girard and Ellen Launstein for their assistance in data collection and entry.
- The United States Department of Agriculture National Institute of Food and Agriculture (Agriculture and Food Research Initiative Competitive Grant no. 2013-68003-20339) for funding this study and my research.

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CHAPTER 1

MILK QUALITY AND MASTITIS, THE ROLE OF DAIRY EMPLOYEES AND THE CULTURAL LAG IN TRAINING – A LITERATURE REVIEW

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The Impact of Mastitis

Bovine mastitis is one of the most important diseases of dairy cattle in the United States (USDA 2007) and continues to cause major economic losses to the dairy industry due to decreased farm productivity and quality of dairy foods (Ma et al., 2000; Losinger, 2005; Cha et al., 2011; Hogeveen et al., 2011). The National Mastitis Council estimates that reduced milk production accounts for 70% of the total loss associated with mastitis (NMC, 2013). While quite variable, losses from clinical mastitis range from $95-200/case (Cha et al., 2011) with lost milk production from clinical cases ranging from 0.37 kg/cow/day to 3.7 kg/cow/day (Bartlett et al., 1990; Seegers et al., 2003; Hagnestam-Nielsen et al., 2009; Halasa et al., 2009). However, additional losses result from discarded milk, treatment costs, and replacement costs (Gruet, 2001; Erskine et al., 2003; Hand et al., 2012; Heikkilä et al., 2012). Clinical mastitis is commonly identified by farm personnel due to symptoms such as abnormal milk, swollen quarters or systemic illness. However, most intramammary infections (IMI) are often subclinical, i.e., there are no visually detectable changes in milk or the udder (Royster and Wagner, 2015). Thus, subclinical IMIs are more difficult to detect and only 25-30% of chronic subclinical infections show clinical signs (Barlow et al., 2009).

Somatic cell counts (SCC) have been used for decades as a general indicator of udder health (Dohoo and Meek, 1982) and are comprised of a mixture of white blood cells including neutrophils and macrophages, as well as epithelial cells (Fox, 2013). Although many factors can affect individual cow SCC over the course of her lactation including days in milk, stress levels, seasonality and natural day to day variation, the most important variable is the presence of IMI in the udder (Dohoo and Meek, 1982; Archer et al., 2013). Likewise, herd level or bulk tank SCC (BTSCC) are highly correlated with the prevalence of IMI in a dairy herd (Erskine et al., 1987).

Phagocytes are the bovine mammary gland's primary response to infection and inflammation (Kehrli and Shuster, 1993). A threshold of 200,000 cells/mL of milk has been used as a benchmark to distinguish between an uninfected and infected udder (Dohoo and Meek, 1982; Schepers et al., 1997; Fox, 2013). Pioneering work by Raubertas and Shook (1982) found that there was a direct linear relationship between milk yield loss and the log 2 transformation of somatic cell count (SCC), with estimates of 0.7 kg of milk lost per day in older cows (0.35 kg in first lactation cows) for each doubling of SCC, or unit increase in linear score. Thus, a cow with a SCC of 200,000 cells/mL (linear score of 4) would lose 0.7 kg of milk per day as compared to a cow with a SCC of 100,000 cells/mL (linear score of 3). However, more recent studies have re-examined the relationship between SCC and milk production losses and may better reflect the current production, management, and genetics of dairy operations than 30 years ago.

Dairy Herd Improvement (DHI) records from over 2,800 dairy herds in Ontario were reviewed to determine the relationship between SCC and milk production (Hand et al., 2012). Similar to the Raubertas and Shook report, the Canadian study also found a positive association between daily milk loss and SCC; but the milk loss associated with increased SCC may be greater than previously suggested, especially in first lactation animals. Lactation milk loss increased from 165 to 919 kg over a lactation as average SCC increased from 100,000 cells/mL to 1,500,000 cells/mL. Unlike the Raubertas and Shook model, the impact of subclinical mastitis on milk yield loss, both in terms of kg of milk per day and percent of daily milk yield, increased with parity and milk production. Thus, the higher the milk production of a cow, the greater the losses related to increased SCC (Hand et al., 2012).

In 2015, analysis of 164,423 individual cow records in Washington, Oregon and Idaho showed that cows with a somatic cell count (SCC) > 200,000 cells/mL at the first DHI test date produced about 700 kg less milk than their herd mates with a SCC < 200,000 cells/mL over the course of the ensuing lactation (Kirkpatrick, 2015). Additionally, cows with high SCC at the first test date are 2.5 times more likely to have a case of clinical mastitis, as well as three times greater risk of being culled within the first 60 days in milk.

At a herd level, increased mastitis also results in lost income from decreased premiums or increased penalties that are applied relative to bulk tank SCC (BTSCC). BTSCC greater than 200,000 cells/mL are associated with decreased productivity per cow, milk shelf-life, and yield of raw milk products such as cheese (Klei et al., 1998; Ma et al., 2000). On a national level, reduced milk production associated with BTSCC ≥ 200,000 cells/mL results in an annual economic loss of $ 3.1 billion to consumers (Losinger, 2005). As of March 31, 2012, the USDA required that dairy exports to the European Union (E.U.) originate from farms with BTSCC at or below 400,000 cells/mL.

Recently, studies have also linked clinical mastitis with reduced reproductive fertility, reporting between 17 to 52 additional open (or non-pregnant) days in cows with a case of clinical mastitis (Ahmadzadeh et al., 2009; Kirkpatrick, 2015). Loeffler et. al (1999) reported a >50% reduction in pregnancy risk three weeks after artificial insemination if cows had a clinical mastitis cases within 3 weeks after breeding. Fuenzalida et. al (2015) also found a decrease in the odds of pregnancy for cows that experienced a case of clinical mastitis during the breeding risk period (BRP) that was defined as 3 days prior to artificial insemination to 32 days after artificial insemination. Pregnancy rates during the BRP were 0.56, 0.67 and 0.75 for cows that had a first episode of clinical mastitis, first episode of subclinical mastitis, or were uninfected, respectively.

Mastitis is the most common reason for antimicrobial drug use on dairy farms for adult dairy cattle (Wagner and Erskine, 2009). In 2014, an estimated 21.7% of the approximately 9 million cows in the U.S. were treated with antimicrobials for this disease (USDA, 2014), equating to over 1.9 million mastitis cases treated annually. Estimates of the percent of farms that use intramammary (IM) infusions varies from 90 to 98% (Zwald et al., 2004; USDA 2009). The use of IM dry cow treatments is also routinely used on many dairy farms to help control mastitis infection rates over the dry period. In a recent survey of 628 dairy herds, 75 % of herds reported use of blanket dry cow therapy (Schewe et al., 2015). In a Wisconsin study, about 80% of all antimicrobial drugs used were for treatment or prevention of mastitis, which included dry cow therapy (Pol and Ruegg, 2007). In a Canadian study, IM administration of antimicrobials was estimated to account for 35% of all antimicrobial use on dairy farms, which was lower than antimicrobials administered systemically (38%; Saini et al., 2012). However, in this study, the accounting of antimicrobial drug use was not just limited to adult dairy cattle.

Several studies have examined attitudes and motivations of producers when it comes to mastitis treatment. In a study of treatment of clinical mastitis in 51 large dairy herds in Wisconsin (Oliveira and Ruegg, 2014), 71% of mastitis cases were treated with IM antimicrobials while another 43% received both IM and systemic antimicrobials. In the United States, no antimicrobials are currently labeled for systemic treatment of mastitis, thus in the Wisconsin study, all systemic treatments were considered as “extra-label.” Other studies have also noted a high proportion of extra-label drug use for the treatment of mastitis. Sawant et al. (2005) surveyed 113 herds from 13 countries and found 18% of herds used ceftiofur in an extra-label manner to treat mastitis. Swinkels et. al (2015) surveyed 38 dairy herds in Germany and the Netherlands and found that 37 of 38 surveyed herds reported to “occasionally” or “frequently extend mastitis treatment.” They hypothesized that giving the best possible treatment gave the producer a feeling of being a “good farmer.” However, none of the farmers expressed concern about the increased treatment costs, wasted milk, prolonged use of antibiotics or the potential of selecting for antibiotic resistant pathogens. Every tanker of milk is tested for beta-lactam residues, which per the USDA, has resulted in a decline over the past decade in positive violating residues (0.012% of tankers positive in 2015). While more than 90% of operations administer drugs that require a milk or meat withdrawal time, only 70% of operations do on-farm testing of milk for residues (USDA, 2014).

Most cases of clinical mastitis on a dairy farm are considered mild or moderate and therapeutic protocols often rely on administration of IM antimicrobial drugs. However, the use of case definitions and criteria to decide if a case should be treated are important parts of treatment protocols. Basic considerations for treatment of clinical mastitis include 1) the severity of the case, 2) if the case is new or recurring 2) the number of quarters affected 3) the existence of concurrent health problems 4) stage of lactation, and 5) causative pathogen (Wagner and Erskine, 2009). In a study by Vaarst et al. (2002), 16 Danish dairy farmers were surveyed on the factors they considered to treat a cow with mastitis. These included 1) symptoms (the severity of the case), 2) cow level factors (e.g., to what extent has a cow fulfilled goals of the producer and herd) 3) herd level factors (the current situation of the herd, including availability of replacement heifers, amount of milk production, milk quota), and 4) opportunities for alternatives (whether the producer regarded other practices as serious alternatives to antibiotic treatment). The authors concluded that symptom level was the dominant deciding factor in severe cases of clinical mastitis although what producers interpreted to be "severe" varied from farm to farm (Vaarst et al., 2002). Despite the importance that dairy producers place on the severity of case presentation, the most important management tool that should be employed in therapeutic decisions for mastitis is the use of records of treatments and outcomes. However, Sawant et al

(2005) found that only 50% of surveyed herds kept written or computerized treatment records for antibiotics. Furthermore only 33 producers (29%) maintained complete records. In a more recent survey, Kayitsinga et al (2017) found only 56% of surveyed herds maintained records of all treated cows and only 49% reviewed records before administering mastitis treatments. Past surveys done by Kaneene and Ahl (1987) of dairy producers in Michigan indicated that insufficient record keeping and poor knowledge about drug withdrawal periods among producers were important factors leading to drug residues in milk.

Thus, mastitis has a variety of both short and long term impacts on a cow's productivity ranging from discarded milk, decreased milk production, and extensive antimicrobial drug use. Case severity and individualized treatment protocols of the farm often determine the course of treatment. However, case definitions are highly variable between operations which also reflects a producer's motivations and behaviors associated with treating mastitis.

Mastitis Control Practices

Controlling mastitis requires a multifactorial approach that includes milking protocols, equipment, cow immune status, and cow environment, such as housing, bedding, and ventilation. Historically, subclinical infections from contagious pathogens such *as Streptococcus agalactiae* and *Staphylococcus aureus* were found to be controlled by, post-milking teat dipping (PMTD), and blanket dry cow therapy (BDCT) with concurrent reductions in BTSCC (Erskine et al., 1987; Goodger et al., 1993; Hogan and Smith, 2012; Schewe et al., 2015). This approach to mastitis control was summarized by the National Mastitis Council as a five point program that includes 1) treat and record clinical cases, 2) post milking teat disinfection, 3) dry cow therapy, 4) cull chronic cases, and 5) milk machine maintenance (NMC, 2013). As the prevalence of contagious mastitis declined, mastitis control evolved to include management practices such as bedding and housing that reduce exposure to environmental pathogens, e.g., *Streptococcus uberis, Klebsiella sp.*, and *Escherichia coli.* Recent surveys demonstrated that dairy producers have widely adopted standard practices associated with mastitis control; post-milking teat dipping, use of dry cow therapy, not using water during udder preparation before milking, and use of free stalls with inorganic bedding are practiced in about 83%, 86%, 78% and 88% of herds, respectively (Jayarao et al., 2004; Dufour et al., 2011; Schewe et al., 2015).

As accepted practices for milk quality have become more widely adopted, and as our understanding of the disease advance, more recent studies have attempted to further discriminate the factors that are the most critical for mastitis control. However, results are variable due in part to the differences in the adoption of control practices, herd demographics, and facilities. Herds that house dry cows in free stalls or loose housing had lower BTSCC than those farms that used tie stalls, stanchions or outside lots. Mattresses and sand bedding for lactating cows and heifers was also associated with lower BTSCC (Wenz et al., 2007; Dufour et al., 2011), as was maintaining dry cow cleanliness and teat disinfection (Chassagne et al., 2005). Barnouin et al. (2004; 2005) did a prospective study of 534 French herds to determine what management practices influenced bulk tank somatic cell counts (BTSCC). The probability of a herd belonging to a low somatic cell score group (top 5th percentile) was associated with: (1) regular use of teat dipping after mammary infusion at dry off; (2) culling cows with recurring clinical mastitis; (3) having experienced people provide herd management practices and (4) feeding a balanced ration. Additionally, use of internal teat sealants have been shown to be beneficial in lowering mastitis. Godden et al. (2003) found that the use of internal teat sealants decreased the risk of developing mastitis over the dry period by 30%. Schewe et. al (2015) also found similar results, with lower BTSCC associated with the use of internal teat sealants and BDCT. However, as in the French study that linked lower BTSCC to the experience of farm personnel, the Schewe et al study found lower BTSCC were associated with the producer's perspective that employees regularly complied with milking protocols.

Milk Quality and Changes in the Dairy Demographic Landscape

Due to extensive research, outreach education and the willingness of dairy producers to adopt proven mastitis control practices, herd average SCC have been decreasing over the past quarter century. (USDA, 2013; Norman, 2015). However, the dairy producer's willingness to consistently practice mastitis control protocols varies and may impact milk quality. A Dutch study found that the management approach and attitudes among herds with low BTSCC (< 200,000 cells/mL) was described as "clean and accurate", as compared to herds with BTSCC between 250,000 and 400,000 cells/mL whose approach was described as "quick and dirty" (Barkema et al., 1999). The low BTSCC herd group were found to have better overall farm hygiene and record keeping than the high BTSCC herd group. In a study done by Khaitsa (2000), producers who perceived that BTSCC had not been a problem, or only a slight problem, had significantly lower BTSCC than farms where BTSCC was perceived to be a moderate or major problem. Thus, the approach and attitudes of the producer, and potentially of all farm personnel, to comply with the farm protocols, contributes to the status of milk quality on a dairy farm.

However, despite the importance of a producer's approach to mastitis control, two major barriers hinder progress for milk quality. The first is the need to further explain dairy producer attitudes and motivations towards mastitis control practices; particularly social variables, that include cultural, economic and environmental variables. The second, and perhaps more important barrier, is the increasing reliance on non-family labor for most dairy herds, resulting from a dramatic increase in herd size and the proportion of milk produced by larger herds.

Over the past two decades, there has been a marked shift in herd size among dairy farms in the U.S. Farms with fewer than 100 cows accounted for 49% of the country's milk cows in 1992, but just 17% of milk cows in 2012. In contrast, farms with at least 1,000 cows accounted for 49% of all milk cows in 2012, up from 10% in 1992 (MacDonald and Newton, 2014). As variability in herd size increases, dairy farms are also becoming increasingly varied in terms of employment practices and organization (Jackson-Smith, 2000). Additionally, farms with more than 500 milking cows now account for 63% of the milk supply in the U. S. (Bewley et al., 2001; Cross, 2006; von Keyserlingk et al., 2013). Thus, an increase in herd size has created a greater need for non-family labor (Bewley et al., 2001), with estimates of one employee for every 80 to 100 cows (Douphrate et al., 2013).

According to census 2000 data, the number of Mexican immigrants in the U.S. labor force nearly doubled from 1990-2000 with estimates ranging from anywhere from 2.6 million to 4.9 million (Jenkins et al., 2009). The actual number of immigrant workers is hard to document for many reasons including: 1) many temporary workers may not have been working at the time of the survey 2) some employers may not have reported "under the table" employees, and 3) employers don't include part time workers (Harrison, 2009b). Regarding the dairy industry, 41 to 50% of dairy farms in the U.S. rely on foreign labor (Baker and Chappelle, 2012; von Keyserlingk et al., 2013) and 88.5% of surveyed immigrants were from Mexico, the remainder were comprised from Central and South America (Harrison et al., 2009a).

There are many obstacles that immigrant employees must overcome. One of the biggest challenges includes language barriers. Dustmann et al. (2003) found that as English fluency increases, employment probabilities increase by about 22%. However, there is a lack of published information regarding the importance of this problem with respect to dairy farms. In studies of farm employees done by Baker and Chappelle and the U.S. Department of Labor, only 26% of surveyed employees were able to speak “some English”, 4% said they spoke English well, and 64% said they had little to no English language ability. Conversely, 68% stated that nobody in a management position spoke Spanish. Illiteracy may further complicate training of farm employees, especially with Spanish speaking employees. There is a need for programs pertaining to language training, cultural understanding, farm management skills and small business development assistance for minority farmers and farm workers (Harrison, 2009b; Baker and Chappelle, 2012).

Even when language is not a barrier, past research has found that miscommunication still occurs between employees and management (Hadley et al., 2002; Román-Muñiz, 2007; Baker and Chappelle, 2012). Román-Muñiz et. al (2007) commented that a communication gap is likely to arise and the problem is further exacerbated where owners do not directly supervise daily tasks. Erskine et al. (2015) documented a pilot study where dairy herd managers and employees were interviewed with a similar set of human resource questions. Managers filled out a paper survey, employees were surveyed with the use of a hand-held clickers and computer acquisition of responses for anonymity. Surveys were also translated into English or Spanish depending on the needs of the employees. While 11 out of 12 management teams believed that they provided primary training for milking, 42% of English speaking and only 14% of Latino workers said that they were trained primarily by managers. From the employee's perspective, most training was provided by other employees or was self-taught.

Immigrants also experience difficulties with community, not only with language but also discrimination and cultural differences (Harrison, 2009a; Hagevoort et al., 2013). In a survey of 267 workers in Wisconsin, 15% said they "didn't go out", or "did nothing" when asked about outside activities (Harrison, 2009a). Safety is also an issue with increased risk of injury, illness, or death occurring among workers with lower education levels, illiteracy and limited proficiency in English (Loh and Richardson, 2004; Smith et al., 2006; DaVila et al., 2011).

When first hired, many employees on dairy farms are inexperienced with dairy work, including tasks such as milking and handling cows. This inexperience, coupled with many dairy producers feeling unqualified to manage and train employees, has created training and knowledge gaps for employees on many dairy farms. Many dairy producers realize that human resource management is a weakness in their operation (Stup et al., 2006) and dairy producers who expand their operations experience more difficulty and less satisfaction with human resources than any other facet of management (Bewley et al., 2001). Bewley et al. also noted that producers who built new facilities spent less time on farm work and more time on managing employees. However, producers who expanded into new facilities reported less difficulty in finding and retaining good employees compared to those producers who only modified their facilities. As the dairy industry is evolving, producers with larger herds spend more time hiring, training and managing employees and rely more on non-family labor. While satisfaction with employee morale and attitude, labor efficiency and ability to get farm work done also seems to increase as herd size increases, non-family labor is generally more expensive, less experienced and less flexible than family labor (Bewley et al., 2001). Producers also recognized that there was a need to change how information was given to employees (Jansen and Lam, 2012).

There has been little published regarding the motivations and attitudes of dairy farm workers, although some studies investigated these social variables in other agricultural enterprises. In 2011, Holmes participated in an observational study on a berry farm in Washington and documented the hierarchy among employees. He found that there is an inverse relationship between job responsibilities and stressors. As control over one's job decreases, anxiety accumulates within positions of lower supervision and responsibility. Kolstrup (2012) surveyed a combined 550 agricultural students, dairy farm workers and employers. Employees ranked the highest satisfaction scores to factors that included: 1) independence at work; 2) provision of free working clothes and 3) working with animals. Priorities for employees that chose to work and remain in agricultural field were 1) fun at work; 2) good leadership; 3) working with animals; 4) pride in the profession, and 5) job security.

There are both external and internal influences on employee job satisfaction in the dairy industry. Larger herds often offer higher cash wages and total compensation, health insurance and housing compared to smaller herds. Qualitative observations show employees also enjoy non-cash benefits but underestimate their value (Fogleman, 1999). Valeeva et al. (2007) found that internal farm performance factors provide more motivation than external factors (including farm penalties or incentives) for employees. Internal non-monetary factors that related to internal esteem and taking pleasure in healthy animals was as equally motivating as monetary factors.

Shift fatigue has been documented in industries including the automotive industry and police work. When comparing an eight vs. twelve hour shift in the automotive industry, it was found that even though reaction time was faster for employees at the end of a twelve hour shift, more errors were documented when compared to the end of the eight hour shift (Mitchell, 2000). Vila et al. (2002) documented how police officers often work twelve hour shifts, noting there are both long term and short term consequences of fatigue. Short term consequences include sleepiness, diminished appetite, dulled recollection and slower reaction times. Long term consequences include increased stress levels and decreased abilities to cope with complex and threatening situations, interference of familial and social relationships that are connected to the community, as well as the perspective needed for sound decision making. However, little is known of the impact that shift fatigue and ergonomics have on the performance of employees on dairy farms.

The demographics of dairy farming in the United States are changing and thus, the needs of the industry are also evolving. Many of the employees that are working on dairy farms now are from other countries and when working in the United States face illiteracy and language barriers. These are barriers that can be overcome with proper training and educational opportunities to encourage employee engagement. However, there is an overall lack of capacity within the dairy industry to provide adequate employee training and education. Understanding employee motivations and their needs will help contribute to employee retention, improve farm productivity, and reduce the cost of employee turnover.

Employee Behaviors and Milk Quality

The application of proven milking protocols is a crucial part of producing high quality milk on a dairy farm by 1) maintaining sanitation, 2) reducing mastitis, 3) harvesting milk effectively and 4) ensuring that abnormal milk, including that from cows treated with antibiotics, does not end up in the food supply. Effective milking is based upon the triad of interactions between the milking system, the cow, and personnel who milk the cows. Employees can be part of a positive milking experience for the cows by practicing proper milking procedures, and moving cows to and from the parlor in a non-stressful manner. Current recommendations for milking procedures from the National Mastitis Council include the following; that a low stress environment needs to be provided for cows, the foremilk and udder should be checked for mastitis, teats should be disinfected with an udder wash solution or pre-dip and then be dried completely with an individual towel, milking units should be attached within 120 seconds after initiation of stimulation and adjusted for proper alignment, vacuum should be shut off before removing units, and teats should be dipped immediately after unit removal with an effective disinfectant (NMC, 2013). Perhaps the three most critical milking behaviors for effective milking are 1) ensuring proper pre-stimulation of teats and time period between stimulation and unit attachment to the udder (lag time), 2) ensuring that units are aligned on the udder properly during milking and that air vents that allow proper milk flow away from the cluster are patent, and 3) not allowing the cows to be overmilked.

The anatomy of the bovine udder divides milk storage; 20% of the milk is held in the milk cistern at the bottom of the udder, known as "cisternal milk", and 80% is in the mammary gland, known as "glandular milk"(Bruckmaier, 2005). While cisternal milk can be readily released, glandular milk which is held in the mammary gland alveoli requires the contraction of myoepithelial cells to move milk through the ducts and into the cistern. Pre-milking stimulation of the teats is necessary to induce a neural reflex arc that causes oxytocin release from the pituitary gland into the circulation, which in turn activates the myoepithelial cells to force ejection of milk from the alveolar space (Bruckmaier, 2005). Weiss and Bruckmaier et al. (2005, 2013) recommend that the duration of pre-stimulation before milking should be for 30-60 seconds, however with low udder filling, longer pre-stimulation of 90 seconds can be helpful, which may not always practical in the parlor environment. They also found that the intensity of stimulation is less important than the duration. However, stimulation does not need to occur all at once and can be split into shorter tactile sessions, minimum of 15 seconds, followed by a latency of 45 seconds. Because of the short plasma half-life of oxytocin, no more than 2 minutes should pass between tactile stimulation and milking unit attachment (Bruckmaier et al., 2013). After initial stimulation, continuously elevated levels of oxytocin are needed through the entire milking process which is typically provided by liner (inflation) stimulation during pulsation. Even greater myoepithelial contraction is needed to eject milk out of an incompletely filled, as compared to, filled alveolus (Bruckmaier, 2007). Therefore, good udder stimulation is even more important for a late lactation cow compared to a cow that has recently calved. Inhibition of milk ejection due to a lack of oxytocin may also be caused by a variety of factors, including unfamiliar surroundings, cortisol related to rough cow handling, or use of exogenous oxytocin injections (Bruckmaier, 2013), .

Unfortunately, as labor costs increase and farm size increases, less time is spent on proper teat stimulation, therefore reducing time for udder preparation (Sandrucci et al., 2007). Proper udder stimulation and lag times relative to milk ejection can be measured by several indicators, however measures of peak milk flow are most commonly used. Bimodal milking, also known as “biphasic milking,” is caused by the disturbance of oxytocin availability to myoepithelial cells which causes a time period between release of cisternal and glandular milk and thus a period when no milk is flowing. This delayed milk ejection has many negative health effects to the cow including penetration of the milking vacuum into the cistern which subsequently collapses the teat cavities, interrupts blood flow, allows the milking clusters to “climb” up the teats, causes air admission and increases bacterial exposure to the teat ends. This disrupts effective milk ejection during the remainder of milking even after delayed milk “let down” has been resolved (Bruckmaier, 2007).

Several factors can cause delayed milk ejection. The most common is inadequate stimulation causing a lack of oxytocin to the myoepithelial cells to induce good milk let down. However, certain cow factors may also contribute to this problem, including longer days in milk (DIM). According to Sandrucci et. al (2007) the percentage of bimodal curves increased throughout lactation; 27% of cows < 150 days in milk (DIM) had bimodal curves and 40% of cows > 150 DIM had bimodal curves. Tancin et. al (2007) also found an association between bimodal milk let down and longer overmilking phases and lower milk yield. This may have long term effects as investigators also found that a longer duration of the decline phase of the milk flow curve seems to have positive correlation with SCC, either for the single quarter or for the whole udder.

The second important practice to ensure effective milking is to alleviate and reduce overmilking. Overmilking is defined as when the milk flow to the teat cistern is less than the flow out of the teat canal (Rasmussen, 2004). Overmilking can be caused by improper automated take off settings on milking units (milking the cows dry) or the use of manual milking (when units are set to continuously milk until they are taken off by milking personnel). Overmilking results in longer unit on times (when units are attached to the udder), and thus longer exposure of teat ends to vacuum. In the short term, this can result in color changes to the teat wall which indicates vascular damage and swelling of the teat canal (Mein, 2001). Vascular changes and swelling causes the flow of milk to be impeded from being expelled efficiently. Over the long term, teat ends become roughened which can lead to increasing rates of clinical mastitis (NMC, 1999; Neijenhuis et al., 2000; Paduch, 2012). Teat end changes can occur with chronic exposure (2 to 8 weeks) from overmilking that can result in teat end roughness and callosity (hyperkeratosis). Other cow variables that can affect teat end hyperkeratosis include teat end shape, cow production level and stage of lactation, as well as machine variables such as slow milking and over milking, take off settings for automatic cluster take offs and pre-milking udder preparation (Mein, 2001). Moderate and severely hyperkeratotic teat ends have a higher risk (ranging from 0.3 to 2.2-fold) of a clinical mastitis event during that lactation than normal teats (Neijenhuis et al., 2001; Breen et al., 2009; Paduch et al., 2012).

Longer unit on times also decrease parlor efficiency by decreasing parlor turnover rate and increasing the time that cows are away from the barn. Increased time that cows wait in holding pens increases the time that they remain standing away from feed and stall rest. Watters et al. (2014) found that providing feed to cows 90 minutes post-milking decreases the risk of intramammary infection. DeVries et. al (2012) also found longer periods of cows standing in the holding pen were associated with poor udder hygiene.

Milking personnel also maintain patent air vents and proper alignment of the milking units. Proper alignment of milking units is crucial for efficient and gentle milking. It also reduces the risk of liner slips which allow atmospheric air to enter the milking unit. This increases the risk of milk splashing upwards towards the open teat orifice and can introduce bacteria into the canal. Air vents help to maintain proper milking vacuum and move milk away from the cow along a vacuum gradient towards the cluster. Vents also help prevent back flushing of milk towards the teat end in case of a slip (LeGassick, 2013).

Along with the cow and milking machine, employees are the third piece of the triad for effective milking. They can be directly responsible for creating an environment for a good milking experience that includes all the points listed above; adequate teat stimulation that induces oxytocin-related milk let down, patent air vents and proper unit alignment, and prevention of overmilking.

Thus, a complete evaluation of milk quality on a dairy farm should not only include the traditional parts of an evaluation such as the milking equipment and the cows, but should also provide insight into the employee's work culture, training and education. As employees often handle and provide care to the animals on the farm daily, their knowledge and behaviors are critical for the success of the milking operation.

Conclusion

Mastitis continues to be a significant problem for the dairy industry. Proven control measures are available and have shown to be successful, however greater reliance on employees has raised new challenges for mastitis control because of a lack of capacity to train and educate personnel to follow accepted mastitis control protocols. This 'cultural lag' in the dairy industry has created a need to further study the labor culture on dairy farms, and find the means to assess employee performance and thus success of employee training. As shown with the Barkema et. al (1999) study, a dairy producers approach to farm management impacts milk quality. If a producer's management style is "quick and dirty" their farms tend to be associated with lower milk quality vs. those producers whose farm management style was “careful and precise”. This dichotomy of producer approaches to mastitis control practices may also exist in a producer’s approach to employee training and management as well, which could potentially impact milk quality and food security. To address this crucial problem, the overall objectives of this thesis are to determine the impact of the labor culture, employee training, and employee behaviors on two critical outcomes of efficient milking, milk let down and prevention of overmilking.

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CHAPTER 2

DELAYED MILK EJECTION IN MICHIGAN DAIRY HERDS

Herd-level variables associated with delayed milk ejection in Michigan dairy herds

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Abstract

The objective of this study was to determine which herd-level variables were associated with delayed milk ejection (bimodal milk let down) in 64 Michigan dairy herds. Median herd size was 294 cows (range 59 to 2,771 cows). For each herd, milking protocols were observed and milk flow dynamics were estimated by use of digital vacuum recorders. Surveys were also administered to the producers to measure mastitis management practices and attitudes. Milk flow dynamics were recorded for a total of 3,824 cow milkings, with a mean of 60 milkings per herd (range of 11 to 154). Backwards multivariable analysis was used to determine which of the 47 herd-level milking and management variables were associated with delayed milk ejection (cows with milk let-down periods between milking cluster attachment and the incline phase of milk flow of > 30 s). Delayed milk ejection occurred in an average of 25% of the cows in each herd (range 0 to 75%). A multivariable model found that the proportion of cows in a herd with delayed milk ejection was negatively associated with mean total time of tactile stimulation during pre-milking routines and positively associated with herd size. In summary, delayed milk ejection is more likely in herds with milking practices that may emphasize parlor efficiency over milking efficiency.

Key words: delayed milk ejection, bimodal milking, milking behaviors

Introduction

Milk ejection is the active transport of alveolar milk through the milk ducts into the cisternal compartment following contraction of myoepithelial cells that surround the mammary alveoli (Bruckmaier and Wellnitz, 2007). Delayed milk ejection (**DME**), most often exhibiting bimodality, is caused by the disturbance of oxytocin availability to myoepithelial cells, which interrupts milk flow between release of cisternal and alveolar milk (Bruckmaier and Blum, 1996; Bruckmaier and Blum, 1998). Delayed milk ejection has negative health effects for the udder, including penetration of the milking vacuum into the cistern which subsequently can collapse the teat cavity and interrupt blood flow (Bruckmaier and Wellnitz, 2007). This may in turn, allow the milking clusters to "climb" up the teats, cause air admission and increase bacterial exposure to the teat ends. This then disrupts effective milk ejection during the remainder of milking, even after DME has been resolved and is associated with decreased milk yield. (Bruckmaier, 2007; Samoré et al., 2011).

Several factors have been associated with increased risk of DME. The most common human behavioral factors are inadequate pre-milking stimulation and improper lag time (Bruckmaier, 2007; Sandrucci et al., 2007; Watters et al., 2011). Weiss and Bruckmaier (2005) recommended that the duration of pre-stimulation before milking should be 30 to 60 s, however with low udder filling, longer pre-stimulation periods of 90 s can be helpful. This amount of stimulation may not be practical in many parlor environments. Other researchers have found that stimulation by stripping before milking did not affect milk flow or yield (Wagner and Ruegg, 2002). Because of the short plasma half-life of oxytocin, no more than 2 minutes should pass between tactile stimulation and milking unit attachment (Bruckmaier et al., 2013).

Additionally, cow factors such as increasing days in milk (**DIM**) may also contribute to DME. According to Sandrucci et al. (2007), the percentage of milk flow curves with DME increases in later lactation; 27% of cows < 150 DIM and 41% of cows > 150 DIM had delayed milk flow curves. This agrees with Kaskous and Bruckmaier (2011) that found a higher proportion of DME in cows with less alveolar filling of milk before milking compared to cows with greater levels of alveolar filling; a factor typical of cows milked more frequently per day or in late lactation.

As herd size increases in the U.S. dairy industry, farms are increasingly reliant on hired labor versus traditional owner-family labor (Baker and Chappelle, 2012; von Keyserlingk et al., 2013). This dynamic may impact milking efficiency; for example, Sandrucci et al. (2007) found that as farm size increases, less time is spent on proper teat stimulation, therefore reducing time for udder preparation. However, other labor variables that may affect milk ejection, or their relative importance to previously identified factors, have not been fully investigated. The purpose of this study was to further explore which herd-level variables are associated with DME.

Materials and Methods

Dairy Farm Selection

This study was part of a larger project in which 124 dairy herds in Florida, Michigan, and Pennsylvania participated in a 15-month trial to develop an evaluation to assess mastitis and antimicrobial drug use. Sixty-four Michigan dairy herds were visited by the investigators twice between January, 2016 and May, 2017. Enrolled herds participated in the Dairy Herd Improvement (**DHI**) individual cow somatic cell count (**SCC**) option and had a herd size ≥ 70 cows. Because the overall objectives of the umbrella project included employee-related factors on milk quality and antimicrobial use on dairy farms, organic dairies and herds that milked with automated milking systems were excluded. All survey information was collected following approval and performed within the guidelines set by the Institutional Review Board of Michigan State University.

Herd Profile and Management Culture

During the initial herd visit, project investigators explained the study design and conducted a herd profile to record milking times and groups, type of milking facility, housing, employee structure, and other general information. Within 30 to 60 d, the investigators returned to conduct a milk quality evaluation that included 1) milking behaviors and proficiency, 2) milking systems, 3) cow environment, 4) monitoring and therapy of infected cows, and 5) farm management culture. To capture information relative to the management culture, we interviewed dairy producers and/or managers with an 84 question survey relative to their mastitis control practices, attitudes and behaviors (Schewe et al., 2015). Additionally, a separate 16 question human resources survey was administered to describe producer/manager beliefs and practices regarding employee communication, training and education. Approximately 90 minutes was needed to conduct the surveys and review the project with each producer.

Milking Dynamics and Parlor Behaviors

We evaluated milking vacuum with VaDia® digital recorders (Biocontrol, Rakkestad, Norway). Four vacuum channels were employed for each individual cow evaluation by attaching 2.4 mm (internal diameter) silicon tubing to the following positions on the milking cluster: 1) rear quarter liner mouthpiece to record vacuum in the mouthpiece chamber (**MPC**), 2) front quarter liner mouthpiece, 3) short milk tube (**SMT**) as a proxy for cluster vacuum, and 4) short pulsation tube to record pulsation. Previous recordings by the investigators from 40 cows had demonstrated the consistency between simultaneous vacuum recordings in the short milk tube and actual cluster vacuum by insertion of a needle into the bowl of the cluster (not reported).

Each cow-milking event was continuously recorded from the time that milking units were attached until units were removed, either automatically by milk flow sensors or manually by employees. We identified four phases of flow intensity: incline, plateau, decline, and overmilking as described by Tančin et al. (2007) for our intrepretive guidelines and determined the following phases for our study, start of milking, start of the incline phase of milk flow, start of overmilking (end of the decline phase and near static levels in the SMT and MPC vacuum), and end of milking. All vacuum recordings were downloaded and then reviewed using the VaDia Suite software (Biocontrol, Rakkestad, Norway) by two investigators (Moore-Foster and Erskine) and inter-operator agreement of interpretation was tested in six herds before the beginning of the trial. We interpreted our vacuum data using the principle that milk vacuum in the cluster is the inverse of milk flow, as suggested by Schukken et al. (2005). More recently, Penry et al. (2018) determined that increasing MPC vacuum is also associated with lower milk flow as a consequence of teat end congestion.

For each cow, the start of the incline phase was marked when the vacuum level in at least one of the two MPC channels decreased to < 13.5 kpa (4 inHg) and the SMT vacuum decreased from maximum and fluctuated by ≥ 3.4 kpa (1 inHg). The time interval between the start of milking (cluster attachment) and the start of the incline phase was then calculated and termed by the VaDia software as "Let Down Time" (**LDT**). The end of milking was determined to occur when vacuum returned to 0 kpa. (Figure 1). We defined cows with a LDT of > 30 s as having DME and those with a LDT of ≤ 30 s as having normal milk ejection. This cut off for DME was based on the distribution of LDT for all cows in the study (Figure 2). Thus, DME was analyzed as a dichotomous variable. Bimodal milk ejection (example in lower plot of Figure 1) was not observed for any cows that had a LDT of ≤ 30 s. Conversely, 96% of cows with a LDT > 30 s demonstrated bimodal milk ejection, and the remaining 4% of the cows in this category demonstrated high MPC vacuum and low SMT vacuum fluctuations (indicative of low milk flow) for a period of time despite a lack of an initial drop in vacuum after cluster attachment (indicative of bimodality).

During the vacuum analysis for each herd, the quality of air hoses, liner alignment, and air vent patency were also recorded. System vacuum capacity was also tested with a “unit fall off test”; and results determined by National Mastitis Council standards (National Mastitis Council, 2012).

In addition to the VaDia and cluster evaluation, we observed milking procedures and protocols to determine the milking routine, the lag time and time of tactile stimulation of teats. A minimum of four milking strings (defined as one side of a parlor) were recorded during milking preparation in parlors. In platform or tie stall milking operations, stimulation and lag times were recorded for at least four cows per unit. When there was more than one person milking, milking behaviors were observed for a minimum of two milking strings for each person.

Parlor Ergonomics

Measures of parlor ergonomics were estimated by determining the width of the parlor workspace, the height from the floor to the platform, light availability, duration of a milking shift, and the availability of breaks during the shift. Lighting in the parlor was measured with a light meter, both in the middle of the parlor floor (mean of three separate locations) and at the level of the teat, under the cow (mean of six to ten locations). Additionally, for parallel, herringbone and side in/side out parlors, we measured the length of the parlor floor to derive an estimate of the minimum linear distance that each person milking cows might travel during a milking shift, tie stall milking systems were excluded. This was calculated by the following formula:

$$\text{Total Distance per Shift} = (D*PTR)*T$$

D = Distance each employee traveled per parlor load (both sides of the parlor) of cows (m/load)

PTR = Parlor turnover rate, or number of milking loads in the parlor per hour (loads/h)

T = shift length (h)

The distance each employee traveled for each parlor load (D) was estimated by measuring the length of the parlor floor multiplied by proportion of stalls that each employee visited during each pass of the milking routine. This distance was then multiplied by the number of passes in the routine for both sides of the parlor and then doubled (to account for forward and reverse direction for each pass).

The formula for total distance (m) each employee traveled per load of cows was:

$$D = (L*P*N)*2^a*2^b$$

L = length of parlor (m)

P= proportion of stalls prepped by employee

N = number of premilking passes per cow

2^a = factor to account for forward and reverse direction between passes

2^b = factor to account for duplication of distance for each side of parlor per load of cows

For example, if one employee milked in a parlor with 20 stalls (10 cows per side) with a 10 m length of the parlor, and three separate passes were made for each cow during preparation or cluster attachment:

$$D = 10\text{ m (L)}*1.0\text{ (P)} *3\text{ (N)} *2*2= 120\text{ m}$$

Statistical Analysis

Dependent Variable

The dependent variable for this study was the proportion of VaDia evaluated cows with DME in each herd. The proportion of cows with DME was entered into Microsoft Excel (Microsoft Corp., Redmond, WA, USA) for data management and SAS (ver. 9.4; SAS Institute, 2012) was used for descriptive and analytical analyses.

Independent Variables

The independent variables were divided into three categories 1) management culture and human resources, 2) employee behaviors and 3) parlor factors. Management culture and human resource variables included milking technician turnover rates (defined as number of milking technicians hired per year divided by number of positions available), as well as survey questions that included frequency of employee training, manager attitudes about parlor turnover rates and how often managers communicated with employees on personal matters. The average pay rate and other benefits were also included, if applicable. Employee behaviors included mean total stimulation time, lag time, distance traveled per shift, number of stalls per pass and parlor flow rates (described as cows milked per hour, cows milked per employee per hour, and milking strings per hour). Parlor factors included rail height, light intensity, frequency of milking per day, if 95% of liners were properly aligned within the cluster (yes = 1, no = 0) and if 95% of air vents on the cluster were open (yes = 1, no = 0).

Scale Factor Analysis

Initially, a frequency distribution was graphed for each independent variable in our model and normality was checked by visually inspecting the results of residual analysis and ANOVA. Scales were constructed with three to five variables that researchers deemed most relevant. Three scales were tested that accounted for pre-milking procedures, management attitudes and parlor flow. However, only the pre-milking procedures scale was significant (Eigenvalue > 1 and Chronbach's $\alpha > 0.7$), which included three variables: mean time of stimulation at first touch, mean total time of tactile stimulation (natural-log transformation), and average lag time (Eigenvalue = 2.04 and Chronbach's $\alpha = 0.75$).

Bivariate Analysis

To decide which independent variables were eligible for the multivariable analysis, associations between the proportion of DME within a herd and explanatory continuous variables were investigated using Pearson's product moment correlation coefficient. For binary (nominal) variables, the dependent variable was compared to the independent variables using a Chi-square goodness-of-fit test. Any variables with an initial cutoff of $P < 0.20$ (2-tails) were considered eligible for inclusion in the multivariable model.

Multiple Linear Regression

Using multiple regression and the type-III F-test, an automated backwards-stepwise elimination procedure was used to build the final multivariable model until only significant covariates ($P <$

0.05) were retained. Biologically relevant two-way (or first-order) interactions were also evaluated in the model, however none were significant. Herd size was also analyzed as a confounder, the change to the coefficients and R^2 values were greater than 10% for mean total time of tactile stimulation. Thus, herd size was included as a confounder in the model. The residual distribution was assessed visually for normality and homoscedasticity.

Results

Median herd size was 294 milking cows and ranged from 59 to 2,771 cows (Table 1). Mean daily milk per milking cow was 36.8 kg, the three-month DHI geometric mean SCC was 136,800 cells/mL and 62/64 herds (97%) employed non-family labor. This was representative of DHI data for herds in Michigan during 2016; mean herd size was reported to be 257 cows, mean daily milk 37.8 kg and mean SCC 157,000 cells/mL (Norman et al., 2017). A total of 3,824 cows (mean of 60 ± 29 recordings per herd) were evaluated by VaDia analysis, which averaged 23.5% of the milking herd. The mean percentage of cows with DME was 25.0% (Table 1; 95% CI 20.1 to 30.0%). Mean time of stimulation during the first pre-milking pass was 8.0 s (95% CI 6.6 to 9.3 s) and mean total stimulation time was 14.2 s (95% CI 11.9 to 16.5 s). Mean lag time, from first stimulation to cluster attachment, was 103 s (95% CI 96 to 111 s). Recording flaws (e.g., tubes that were disconnected during milking, milking clusters that fell off the udder during milking and were re-attached, battery failure, etc.) resulted in less than 5% of the VaDia recordings; cows with these events could not be accurately assessed for milk flow dynamics relative to DME and were excluded.

Based on the bivariable analysis, 28 variables were significant at $P < 0.20$, however nine variables with the lowest P-values and that were most biologically significant were chosen for multivariate analysis based on the following categories: 1) herd characteristics 2) employees 3) parlor and 4) pre-milking procedures (Table 2). Herd size (natural log), frequency of milkings per day, number of milking stalls, milking shift length, cows milked per full time employee-hour, number of cows milked per hour (natural log), mean lag time, mean stimulation time (natural log transformation), and mean light illumination in the parlor (candela) were all included in the multivariate analysis.

Using backward stepwise regression, the final multivariable model found that total mean stimulation time (natural log) to be negatively and herd size (natural log) to be positively associated with the proportion of cows with DME in a herd (Table 3).

Because of herd size being retained in the final model, we performed a two sample t-test to compare means for each of the eligible variables, stratified by herd size, to better understand if exclusion of some of the eligible variables was potentially explained by association with herd size (Table 4). The cut-off point selected for large (≥ 300 cows) and small (< 300 cows) dairies was based on the criteria that we used for the umbrella project of the present study (Schewe et al., 2015). Other than milking frequency, mean lag time, and illumination, means for all other variables differed ($P < 0.05$) between small and large herds. Total stimulation time in smaller herds (19.2 s) was more than twice that of larger herds (8.8 s). The effect of stimulation time on DME was tested for an interaction with herd size, but was not significant ($P = 0.67$).

Discussion and Conclusions

Our intent was to determine which herd variables, and their estimated relative importance, may influence the extent of DME in dairy herds. The 64 herds in this study had a mean geometric SCC below the U.S. and Michigan DHI average. Even among this population of herds, we found that on average, 25% of cows had delayed milk flow after cluster attachment, which was similar to past research that reported proportion of cows with DME between 22% to 35% (Sandrucci et al., 2007; Samoré et al., 2011; Watters et al., 2011).

In our study, herds that stimulated teats for a longer duration of time had a lower proportion of cows with DME. This is similar with previous literature that also found pre-milking stimulation is an important precursor for oxytocin release to induce milk ejection (Weiss and Bruckmaier, 2005; Bruckmaier, 2013). Additionally, Watters et al. (2015) reported that the frequencies of bimodal milking among cows that had clusters attached immediately, attached after dipping and forestripping followed by a 30s lag time, or attached after dipping, forestripping followed by a 90s lag time, were 21%, 14%, and 7%, respectively. In a study that was similar in size to ours (nearly 2,500 cows), Sandrucci et al. (2007) reported that bimodal milk ejection decreased from 47% for cows with no udder preparation to 30% for cows that were cleaned and forestripped. As much as 60 s of stimulation has been suggested for efficient milk ejection, but stimulation of at least 15 s can induce milk ejection, if a lag time of at least 45 s is included (Wagner and Ruegg, 2002; Weiss and Bruckmaier, 2005; Bruckmaier, 2013). These goals were similar to the mean total stimulation time (14.2 s) and lag time (103 s) observed in our study. However, the duration of both stimulation and lag time may not be as critical for efficient milk ejection in cows that have greater udder filling at milking, such as cows in early lactation, as compared to cows in later lactation (Kaskous and Bruckmaier, 2007).

Our study disagrees with Wagner and Ruegg (2002) who found that stripping teats before milking was not associated with milk flow rates, milk yield or unit on times. However, in that study, only 24 multiparous cows from one farm were included and were milked twice per day. Furthermore, both groups of cows (pre-stripped or not pre-stripped) in that study were vigorously dried with towels for 10 to 15 s before cluster attachment, although this procedure was done just before cluster attachment. In our study, we had considerable diversity in milking systems and protocols, and 41% of herds (26 of 64) were milked three times per day. Thus, our project may have offered a broader scope of variables that need to be considered in the relationship between stimulation and DME.

Sandrucci et al. (2007) found that as farm size increased, less time was spent on teat stimulation, therefore reducing time for udder preparation. Our study agreed with these results, in finding that total stimulation time in smaller herds was more than twice that of larger herds. Conversely, the length of a work shift, the number of cows that were milked per employee-hour and the number of milking units each employee operated during the milking routine were greater in larger herds. The increased workload of employees in larger herds compared to smaller herds suggests there may be more emphasis on cow throughput, or parlor efficiency, in larger dairies. Thus, taken together with the increased risk of DME, larger herds may be sacrificing milking efficiency for parlor efficiency. Additionally, larger dairies have more complex employee structures and many dairies report difficulty in training and maintaining protocols, which is associated with higher bulk tank SCC (Erskine et al., 2015; Schewe et al., 2015). This problem could be potentially exacerbated in herds that have a protocol culture that leads to a higher proportion of cows with DME.

Surprisingly, we did not find an association between DME and lag time between preparation and cluster attachment. Previous reports found that lag times are a key factor in reducing bimodal milk flow and improving overall milking time efficiency (Weiss and Bruckmaier, 2005; Watters et al, 2012). Additionally, the frequency of bimodal milk ejection among cows without a lag interval was 54%, but decreased to 36% and 24% for cows with a lag time of < 60 s and ≥ 60 s, respectively (Sandrucci et al., 2007). However, in our study herds the mean lag time across all herds was within the suggested goals for efficient milk ejection, and the minimum was 33 s. Thus, the overwhelming proportion of herds had a lag time that was considered to be sufficient to augment oxytocin-induced milk ejection, which could have masked the importance of this variable in our model. In contrast, the range of variation in teat stimulation was nearly 20 fold across herds which allowed for more discrimination of comparisons among our study herds. Past research has also suggested an overriding effect of teat stimulation relative to other factors (Weiss and Bruckmaier, 2005; Ambord and Bruckmaier, 2009). Thus, the more critical question raised from this study may regard why some herds attain more stimulation than others.

There were several limitations in this study, e.g., our inability to reliably evaluate vacuum dynamics in cows that had a milking cluster fall off during milking. It is possible that some of these interruptions in milking may be related to DME. However, the proportion of these events was low relative (< 5%) to the total number of cows evaluated and in most instances, determining the time points of the milking vacuum curve that included a detached milking unit was deemed to be highly subjective.

To our knowledge, this is the largest study that has used vacuum recordings, rather than an electronic milk flow meter, as an indicator for milk flow dynamics. Despite this extrapolation, the distinct partitioning of cows that began the start of the incline phase of milking either ≤ 30 s or those that were distributed > 30 s was remarkable and readily apparent when reviewing a scatterplot (not shown) of the histogram in Figure 2. Our dichotomous criteria for DME attained very similar results in terms of the proportion of milkings that resulted in delayed LDT and bimodal ejection in previous studies (Sandrucci et al., 2007; Samoré et al., 2011) and the association between stimulation and DME.

The sample size of cows within each herd depended on herd size, milking shift length, and cow throughput while milking. In smaller herds, (milking shifts less than four hours) we were present throughout the entire milking. However, especially in larger herds, it was difficult to evaluate all milking groups of cows across all employee shifts. Thus, in herds with short intervals between milking shifts, we recorded milking events in portions of two consecutive shifts to gain a wider perspective of milking behaviors. Also, we attached VaDia recorders on several milking clusters in each herd to capture any variation resulting from milking position among cows. Finally, numerous individual cow factors such as stage of lactation, genetics, teat anatomy and parity have been reported as influencing milk ejection, which were not accounted for in our herd-level analyses.

Summary

Decreasing the amount of stimulation during the pre-milking routine was the most critical factor that increased the likelihood of DME in dairy herds. Increased frequency of DME was more likely as herd size increased. Although other variables were found to be associated with DME from bivariable analysis, the low level of variation among herds for some variables such as lag time, or the effect that herd size may have on other variables, possibly masked the importance of these variables in our multivariable model. Given the strength of the relationship between teat stimulation and DME in our model, further research should investigate the management procedures that are directly associated with teat stimulation.

Acknowledgements

This project was supported by Agriculture and Food Research Initiative Competitive Grant no. 2013-68004-20439 from the USDA National Institute of Food and Agriculture. The authors would like to acknowledge participating dairy producers and their employees for their willingness to aid in data collection. Also, the authors thank Leah Girard, Ellen Launstein, Caitlin McNichols and Trevor Walling for their technical assistance.

APPENDICES

Appendix A. Tables

Table 1. Descriptive data of herd profile and management culture variables from 64 Michigan dairy herds.

Variable	Mean (LCL, UCL)[2]	Minimum	25th percentile	Median	75th percentile	Maximum
Percentage of cows with DME[1]	25.0 (20.0, 30.0)	0	6.8	23.3	32.8	75.0
Mean total stimulation time (s)	14.2 (11.9, 16.5)	2.4	7.8	11.2	17.1	40.8
Median overmilking (s)	47.2 (38.6, 55.9)	9.0	21.0	40.0	61.5	201
Herd size (Milking cows)	451 (324, 578)	59	136	294	484	2,771
Milking frequency per day	2.41 (2.28, 2.52)	2.00	2.00	2.00	3.00	3.00
Milking units in parlor or barn	20.5 (17.3, 23.7)	5.00	12.00	16.00	24.00	72.00
Time parlor in operation per day (h)	12.4 (10.9, 14.1)	3.00	7.00	12.50	17.00	24.00
Employee shift length (h)	5.2 (4.5, 5.9)	1.3	3.0	4.4	6.9	12.0
Employee break length (min)	10.2 (4.7, 15.8)	0.0	0.0	0.0	0.0	90.0
Number of milking personnel per shift	2.0 (1.8, 2.2)	1.0	2.0	2.0	2.0	5.0
Milking personnel did other chores during milking shift[3]	0.34 m (0.05, 0.64)	0.00	0.00	0.00	0.00	9.00

(Table 1 cont'd)

Number of milking units operated per milking personnel	10.6 (9.4, 11.8)	2.5	8.0	10.0	12.0	24.0
Parlor turnover rate (number of times the parlor emptied and filled in an hour)	4.4 (4.1, 4.6)	2.8	3.7	4.3	4.6	8.9
Number of cows milked per h	85 (71, 100)	32	49	67	103	360
Number of cows milked per h per individual milker	45 (40, 49)	19	32	39	56	120
Proportion of milking employee turnover per yr	0.47 (0.30, 0.63)	0.00	0.00	0.33	0.50	3.00
Proportion of total farm employee turnover per yr	0.40 (0.24, 0.56)	0.00	0.00	0.25	0.50	3.00
Hourly pay[6] ($)	9.79 (8.88, 10.70)	0.00	10.00	11.00	11.50	15.00
Other benefits received[3]	0.66 (0.53, 0.77)	0.00	0.00	1.00	1.00	1.00
Mean lag time (s)[4]	103 (96, 110)	33	84	102	123	165
Mean time of stimulation at first touch (s)	8.0 (6.6, 9.3)	2.0	3.6	6.3	11.2	21.1
Are cluster vent holes open?[3]	0.80 (0.70, 0.90)	0.00	1.00	1.00	1.00	1.00
Are liners properly installed?[3]	0.94 (0.88, 1.00)	0.00	1.00	1.00	1.00	1.00
Mean illumination milking area (candela)	488 (387, 589)	11	199	421	650	1,845

(Table 1 cont'd)

Mean illumination at the level of the teat (candela)	48 (37, 60)	6	17	33	66	251
Length of the parlor (m)	9.68 (8.40, 10.96)	0.00	6.79	8.40	12.05	27.45
Number of passes per cow during milking prep	2.7 (2.5, 2.9)	1.0	2.0	3.0	3.0	4.0
Number of cows prepped per pass	4.9 (4.45, 5.5)	0.0	3.0	4.5	6.0	10.0
Proportion of stalls prepped per milking personnel	0.59 (0.53, 0.65)	0.20	0.50	0.50	0.50	1.00
Distance traveled per milking personnel per milking shift (m)	483 (400, 566)	108	200	383	614	1417

[1] DME=Delayed Milk Ejection; time between milking cluster and milk let down > 30s
[2] LCL, UCL=Lower and Upper Confidence Limits
[3]0 = no and 1 = yes
[4]Time from first touch to unit attachment, seconds
[5]Pay of $0.00 was reported for some family members

Table 2. Bivariate analysis results for explanatory variables of herd-level proportion of cows with delayed milk ejection in 64 Michigan dairy herds

Variable	P-value
Herd size (natural log)	<.0001
Milking frequency per day	0.06
Number of milking units	0.0004
Employee shift length (h)	0.0048
Cows milked per fulltime employee-hour (natural log)	0.0054
Milking units operated per employee	0.0078
Mean lag time (s)	0.0080
Mean total stimulation time (s; natural log)	<.0001
Mean illumination in the parlor (candela)	0.0256

Table 3. Final linear model for associations between delayed milk ejection and herd-level variables in 64 Michigan dairies

Parameter	Estimate	SE	P-value	R^2
Intercept	4.32	2.38	0.074	0.356
Mean total stimulation time (natural log)	-1.30	0.43	<.005	
Herd size (natural log)	0.599	0.28	0.034	

Table 4. Comparison of means for eligible independent variables for multivariable model between small (<300 cows) and large herds (≥300 cows) in 64 Michigan dairy herds

Variable	Small herds mean (SEM)	Large herds mean (SEM)	P-value
Milking frequency per day	2.47 (0.09)	2.33 (0.09)	0.27
Number of milking units	13.47 (0.96)	26.70 (2.50)	<.05
Employee shift length (h)	3.52 (0.27)	6.82 (0.46)	<.05
Cows milked per full-time employee hr (natural log)	3.58 (0.06)	3.85 (0.07)	<.05
Units operated per employee	8.67 (0.50)	12.35 (0.94)	<.05
Mean lag time (s)	110.0 (5.70)	96.90 (4.70)	0.08
Mean total stimulation time (s, natural log)	2.82 (0.10)	2.16 (0.09)	<.05
Mean illumination in parlor (candela)	396 (73)	564 (68)	0.10

Appendix B. Figures

Figure 1. The upper plot is an example of VaDia® digital recording showing uninterrupted milk ejection. Vacuum is recorded (kpa) on the vertical axis. Each hash mark indicates a 15 s time interval on the horizontal axis. Channel 1 (red) is indicates rear mouthpiece chamber vacuum, channel 2 (blue) front mouthpiece chamber vacuum, and channel 3 (green) short milk tube vacuum. Symbols mark the start of milking (↓), start of incline phase of milk flow (▲), and end of milking (■). The lower plot is an exxample of VaDia® digital recording showing bimodal milk ejection. Vacuum is recorded (kpa) on the vertical axis. Each hash mark indicates a 15 s time interval on the horizontal axis. Channel 1 (red) indicates the rear mouthpiece chamber vacuum, channel 2 (blue) indicates the front mouthpiece chamber vacuum, channel 3 (green) indicates the short milk tube vacuum as a proxy for cluster vacuum. Symbols mark the start of milking (↓), start of bimodal ejection (●), start of incline phase of milking (▲), and end of milking (■).

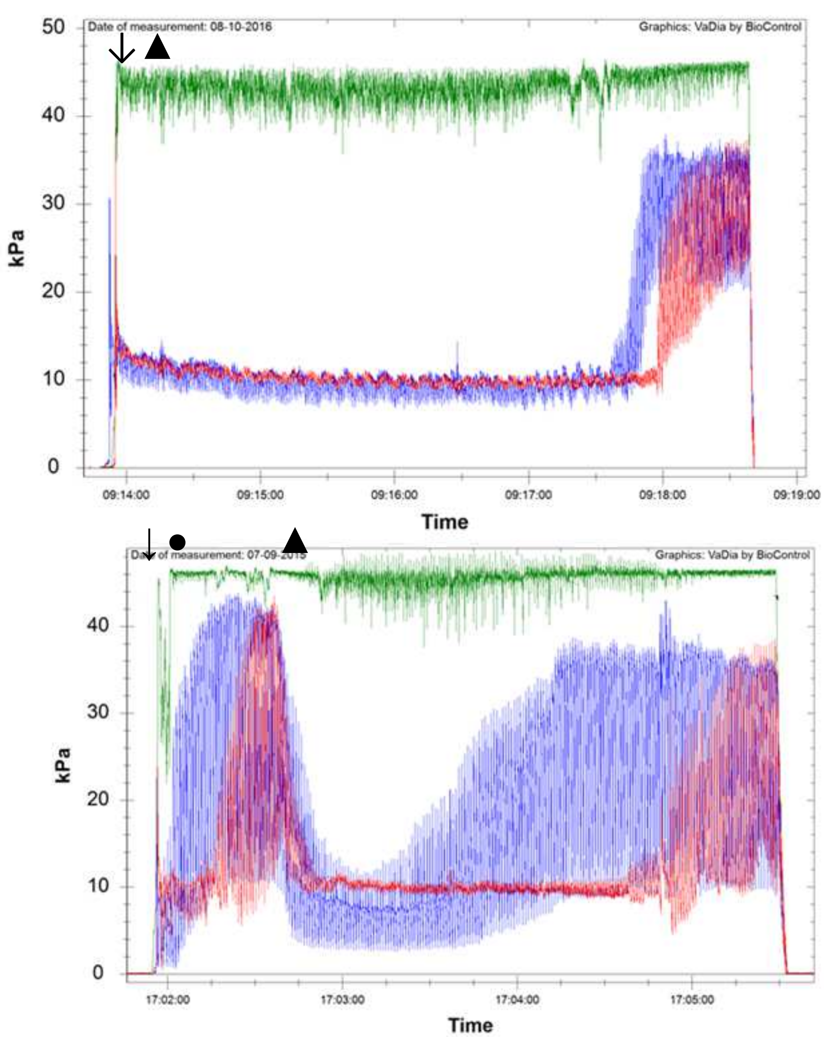
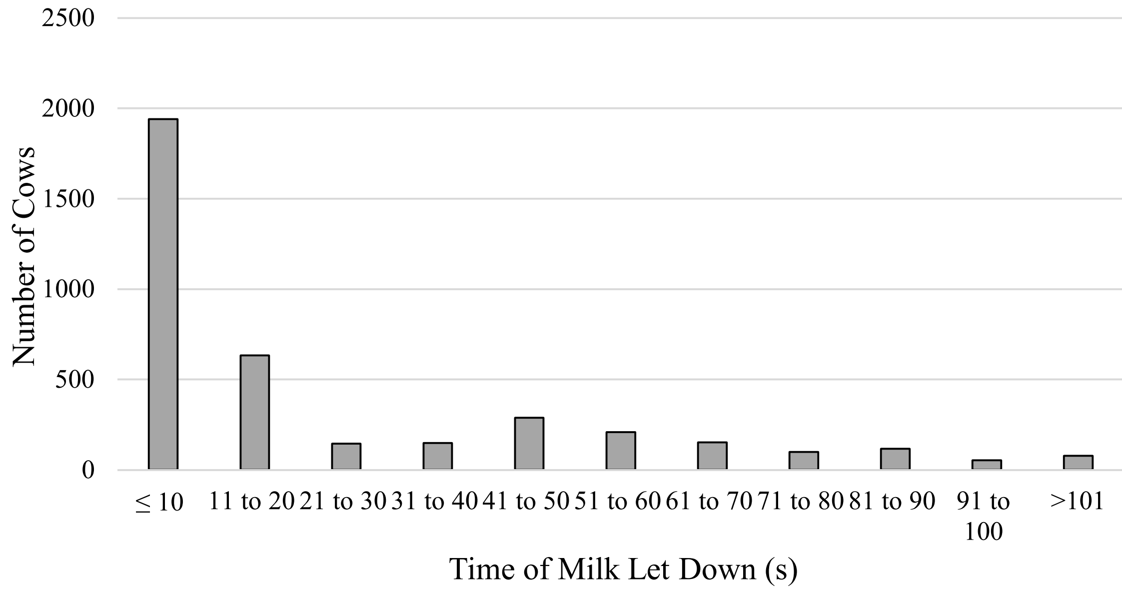


Figure 2. Histogram of time period between cluster attachment and attaining the incline phase of milk ejection (Time to milk let down) for 3,824 cows as recorded by digital vacuum.



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CHAPTER 3

STIMULATION TIME IN MICHIGAN DAIRY HERDS

Herd level variables associated with premilking stimulation time in Michigan dairy herds

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Abstract

The objective of this study was to determine the herd level variables that were associated with total stimulation time during the premilking routine in 64 Michigan dairy herds with non-family employees. The mean herd size was 452 cows (range 59 to 2,771 cows) and the three month DHI geometric mean SCC was 136,795 cells/mL. For each herd, surveys were administered to the producers to gather mastitis management practices and attitudes. Additionally, milking protocols were observed and milk flow dynamics were measured by use of digital vacuum recorders. Backwards multivariate regression analysis was used to determine which of 47 herd-level milking and management variables were associated with mean duration of total stimulation time. Mean total stimulation time was 14.2 s (range of 2.4 to 40.8 s) and was positively associated with increasing lag time (time interval between first stimulation and cluster attachment). Total stimulation time was negatively associated with greater time intervals between milkings and increasing number of passes to each cow in the premilking routine. In summary, increased stimulation time is more likely in herds that foster a lower sense of urgency of cow throughput during milking, as evidenced by an association with longer lag times despite fewer preparation passes per cow and longer intervals between milkings.

Key words: stimulation time, milking protocols, employee management

Introduction

The anatomy of the bovine udder divides milk storage; 20% of the milk is held in the milk cistern, known as “cisternal milk”, and 80% is in the alveoli and ductules, known as “alveolar or glandular milk” (Bruckmaier, 2005). While cisternal milk can be readily released, glandular milk requires the contraction of myoepithelial cells that surround the mammary alveoli to eject the milk through the ducts into the cisternal compartment (Bruckmaier and Wellnitz, 2007). Premilking stimulation of the teats is necessary to induce a neural reflex arc that causes oxytocin release from the pituitary gland into the circulation, which in turn activates the myoepithelial cells to force milk ejection (Bruckmaier, 2005). Weiss and Bruckmaier (2005) recommended that the duration of pre-stimulation before milking should be 30 to 60 s, however with low udder filling, longer pre-stimulation periods of 90 s can be helpful, which may not be practical in some parlor environments. Also, the intensity of stimulation is less important than the duration (Weiss and Bruckmaier, 2005). However, stimulation does not need to occur all at once and can be split into shorter tactile sessions, followed by a latency of 45 s (Bruckmaier, 2013). Because of the short plasma half-life of oxytocin, no more than 2 minutes should pass between tactile stimulation and milking unit attachment (Bruckmaier, 2013). As greater myoepithelial contraction is needed to eject milk out of an incompletely filled, as compared to, filled alveolus (Bruckmaier, 2007), udder stimulation is more important for late lactation cows as compared to recently calved cows (Sandrucci et al., 2007). Additionally, increased risk of bimodal milk ejection has been pre-associated with inadequate premilking stimulation (Sandrucci et al., 2007; Bruckmaier, 2013; Watters et al., 2015), although other researchers have suggested that stimulation by stripping before milking did not affect milk flow or yield (Wagner and Ruegg, 2002).

As herd size increases in the U.S. dairy industry, farms are increasingly reliant on hired labor versus traditional owner-family labor (Baker and Chappelle, 2012; von Keyserlingk et al., 2013). This dynamic may impact milking efficiency; for example, Sandrucci et al. (2007) found that as farm size increases, less time is spent on proper teat stimulation, therefore reducing time for udder preparation. Recently, we completed a study that found that inadequate premilking stimulation and increasing herd size were the most important variables that are associated with increased bimodal milking (Moore-Foster et al., 2018). Thus, in order to further elucidate the factors related to milking efficiency, the objective of this study was to determine the herd level variables, including labor culture, that were associated with the duration of premilking stimulation in 64 Michigan dairy herds.

Materials and Methods

Dairy Farm Selection

This study was part of a larger project in which 124 dairy herds in Florida, Michigan, and Pennsylvania participated in a 15 month trial to develop an evaluation to assess mastitis and antimicrobial drug use. The 64 Michigan dairy herds that participated in the larger study were visited by the investigators twice between January, 2016 and May, 2017. Enrolled herds participated in the Dairy Herd Improvement (**DHI**) individual cow somatic cell count (**SCC**) option and had a herd size > 70 cows. Because the overall objectives of the umbrella project included employee-related factors that might impact milk quality and antimicrobial use on dairy farms, organic dairies and herds that milked with automated milking systems were excluded.

Herd Profile and Management Culture

During the initial herd visit, project investigators explained the study design and collected a herd profile to record milking times and groups, type of milking facility, housing, employee structure, and other general information from surveys and observation. Later, the investigators returned to conduct a milk quality evaluation that included 1) milking behaviors and proficiency, 2) milking systems, 3) cow environment, 4) monitoring and therapy of infected cows, and 5) farm management culture. To capture information relative to the 5) management culture, we interviewed dairy producers and/or managers with a survey relative to their mastitis control practices, attitudes and behaviors (IMPAB). Additionally, a separate human resources survey was administered to describe the farm management culture's producer/manager beliefs and practices regarding employee communication, training and education. All survey information was collected following approval and within the guidelines of the Institutional Review Board of Michigan State University.

Milking Dynamics and Parlor Behaviors

While assessing milking behaviors, we evaluated milking vacuum from 3,862 cows (mean of 60 ± 29 recordings per herd) with VaDia® digital recorders (Biocontrol, Rakkestad, Norway). The methods and interpretation of this analysis were previously described and used to determine the proportion of cows within a herd with delayed (bimodal) milk ejection (Moore-Foster et al., 2018). Additionally, the quality of air hoses, liner alignment, and air vent patency were recorded.

In addition to the VaDia and cluster evaluation, we observed milking protocols to determine the milking routine, the time interval between each preparation step and cluster attachment (lag time) and time spent stimulating the teats. We defined the total duration of teat stimulation (**TS**) as the cumulative time spent applying tactile stimulation to the teats, exclusive of the time period between periods of tactile stimulation. For our analysis, we included wiping, drying, and stripping of the teats, or use of automated teat brush equipment, but not spraying or dipping of teats with a germicide where no direct tactile contact was made. A minimum of four milking strings were recorded during milking preparation in parlors. In platform or tie stall milking operations, stimulation and lag times were recorded for at least four cows per cluster. When there was more than one person milking, milking behaviors were observed for a minimum of two milking strings for each person.

Parlor Ergonomics

Measures of parlor ergonomics were estimated by determining the width of the parlor workspace, the height from the floor to the platform, light availability, duration of a milking shift, and the availability of breaks during the shift. Lighting in the parlor was measured with a light meter, both in the middle of the parlor floor (mean of three separate locations) and at the level of the teat, under the cow (mean of six to ten locations). Additionally, for parallel, herringbone and side in/side out parlors, we measured the length of the parlor floor to derive an estimate of the minimum linear distance that each person milking cows might travel during a milking shift. For tie stall operations, we estimated the median linear distance traveled between cows during preparation and multiplied this distance by the number of cows that were milked by each employee. The formula to calculate this distance was previously described (Moore-Foster et al., 2018).

Statistical Analysis

Dependent Variable

The dependent variable for this study was mean TS during the premilking routine in each herd, as determined by observation by the researchers. This data was entered into Microsoft Excel (Microsoft Corp., Redmond, WA, USA) for data management and imported into SAS (ver. 9.4; SAS Institute, 2012) for descriptive and statistical analyses.

Independent Variables

The independent variables were divided into three categories 1) management culture and human resources, 2) employee behaviors and 3) parlor factors. Management culture and human resource variables include milking technician turnover rates (defined as number of milking technicians hired per year divided by number of positions available, reported by the producer), as well as survey questions that include frequency of employee training, manager attitudes about parlor turnover rates and how often managers communicate with employees on personal matters. Also, herd compensation including pay rate, and if applicable, other benefits were recorded. Employee behaviors included lag time, estimated distance traveled in the parlor per shift, number of stalls per milking preparation pass and parlor flow rates (described as cows milked per hour, cows milked per employee per hour, and milking strings per hour). Parlor factors include rail height, light intensity, how many times cows were milked per day, and if 95% of liners were properly aligned (yes = 1, no = 0) led and if 95% of air vents on the cluster were patent (yes = 1, no = 0).

Scale Factor Analysis

Initially a frequency distribution was set up for each independent variable in our model and normality was checked. We performed Principal Component Factor Analysis to determine if it was possible and appropriate to combine independent variables into composite scales or factors to reflect for management attitudes and parlor flow variables, however alpha and Eigenvalues were not significant for any scales (Eigenvalue >1 and Chronbach's α >0.7).

Bivariate Analysis

Right skewed continuous level variables were log-transformed before the bivariate analysis so normality was attained. To decide which independent variables should be included in the model for multivariate analysis, associations between TS and explanatory continuous variables were investigated using Pearson's product moment correlation coefficient. For binary (nominal) variables, the dependent variables were compared to the independent variables using an Adjusted Wald test for the significance of the relationship. Any variables with an initial cutoff of $P < 0.20$ (2-tails) were considered eligible for inclusion in the multivariable model.

Multiple Linear Regression

Using multiple regression and the type-III F-test, an automated backwards-stepwise elimination analysis was used to build the final multivariable model until only significant covariates ($P < 0.05$) were retained. To test for potential multicollinearity, interactions were also checked, however no significant relationships were found. Herd size was also analyzed as a confounder, the change to the coefficients and R^2 values were minimal for the explanatory variables of 1) lag time and 2) number of passes during the prep procedure, However the R^2 was greater than 10% for shift length. Thus, herd size was considered as a confounder in the model. The residual distribution was assessed visually for normality and homoscedasticity.

Results

The mean herd size was 451 (median: 294) milking cows, ranging from 59 to 2,771 cows (Table 1). 94% (61/64) of herds milked with automatic cluster detachers. Mean daily milk production for each herd was 17,848 kg [95% Confidence Interval (**CI**): 16,404 to 23,324 kg]. The three-month DHI geometric mean SCC was 136,795 cells/mL and 62/64 herds (97%) reported using hired labor. These statistics are comparable to the average farm in the U.S. as reported by USDA With 93% of large farms using ATD, the U.S. average bulk tank SCC at 194,000 cells/mL and 83% of surveyed herds reporting they hire non-family labor (USDA, 2014; Determining U.S. Milk Quality Using Bulk-Tank Somatic Cell Counts, 2015, 2016).

Based on the bivariate analysis, 13 variables were significantly related to TS (Table 5) in the following categories: 1) management culture and human resources – herd size, hours of operation per day for the milking system, employee (or manager) shift length (includes time spent milking and additional chores, if shift length spanned multiple milking shifts, break length was deducted), break length for employees during their shift, number of milking units operated per employee during premilking preparation, number of passes to each cow in the preparation routine, 2) employee behaviors - number of cows per employee (or manager) hour prepped in the parlor, mean lag time , and 3) parlor factors - number of operating milking units, 24 h milk production, the number of cows milked per hour, rail height, and illumination in the milking workspace. Using backward stepwise regression, our preliminary multivariate regression found number of passes in the premilking routine and herd size (natural log) to be negatively associated with mean TS (Table 6). Mean TS was positively associated with mean lag time of the premilking routine.

Because of herd size being retained in the final model, we performed a two sample t-test to compare means for each of the eligible variables, stratified by herd size, to better understand if exclusion of some of the eligible variables was potentially explained by association with herd size (Table 7). Means between large and small herds for cows milked per hour and shift length differed ($P < 0.05$). The cut-off point selected for large (≥ 300 cows) and small (< 300 cows) dairies was based on the criteria used for the umbrella project of the present study (Schewe et al., 2015).

Discussion and Conclusions

The impetus to investigate TS as the outcome variable in this study was a previous analysis of from the same 64 dairy herds that determined that herd size and TS are the two key factors that are associated with delayed milk ejection, or bimodal milk let down (Moore-Foster et al., 2018). This agreed with other studies that described the importance of udder preparation, including forestripping and adequate lag times, in improving milking efficiency and decreasing bimodality (Sandrucci, et al., 2007; Bruckmaier, 2013; Moore-Foster et al., 2018). For example, in a study that was similar in size to ours (nearly 2,500 cows), Sandrucci et al. (2007) reported that bimodal milk ejection decreased from 47% for cows with no udder preparation to 30% for cows that were cleaned and forestripped.

As much as 60 s of stimulation has been suggested for efficient milk ejection, but stimulation of at least 15 s before milking is ideal for optimal milk let down, if a lag time of at least 45 s is included (Wagner and Ruegg, 2002; Weiss and Bruckmaier, 2005; Bruckmaier, 2013). These guidelines were similar (mean TS; 14.2 s), or exceeded by (mean lag time; 103 s) observed behaviors in our study. However, the duration of both stimulation and lag time may not be as critical to promote efficient milk ejection in cows that have greater udder filling at milking, such as cows in early lactation, as compared to cows to cows in later lactation (Kaskous and Bruckmaier, 2007). In a Wisconsin study, stripping as part of premilking routine did not increase milk flow or yield in cows compared to cows that were not stripped (Wagner and Ruegg, 2002). However, both stripped and non-stripped cows were vigorously dried for 10 to 15 s just before cluster attachment (Wagner and Ruegg, 2002). In our study, only 54% of herds stimulated teats > 10 s during the initial tactile pass (germicide application excluded). This indicates that many herds might have an opportunity to increase milking efficiency by increasing the proportion of stimulation earlier in the routine to optimize lag time intervals.

Our results determined that as the number of passes in the premilking routine and herd size increase within herds, TS decreased. Conversely, as the lag time of the routine increased, TS increased. It seems paradoxical that fewer passes in a routine but a longer lag time are both associated with greater TS. However, this may suggest that herds with greater TS have a routine that results in more stripping and wiping for each cow and less travelling between cows. This is underscored by the trend (Table 7) that smaller herds averaged more TS and lag time than larger herds. Herd size was determined to be a confounder in this analysis. Thus, the impact on TS of a number of explanatory variables that were found to be strongly correlated on bivariate anaylsis, such as shift length, the number of cows milked per hour, and the the number of milking units, were likely masked due to herd size.

Collectively, our analysis suggests that a milking routine culture that promotes milking efficiency as compared to parlor efficiency results in better TS of the teats and as found in a previous report (Moore-Foster et al., 2018) less bimodal milking. For example, personnel in smaller herds, who milk cows in shorter time shifts, that are under less pressure to finish milking before the next milking shift begins, or don't need to make as many passes to each cow before cluster attachment, may be more willing to strip and dry teats more thoroughly. Sandrucci et al (2007) found that as farm size increases, less time is spent on proper teat stimulation, therefore reducing time for udder preparation and increasing bimodality. Our study agreed with these results, mean TS in smaller herds (16.8 s) was nearly twice that of larger herds (8.7 s) Previously, we also found an association between greater herd size and a greater proportion of cows with delayed milk ejection (Moore-Foster et al., 2018). In contrast, the USDA-NAHMS Dairy 2014 survey cited that 86% of herds with ≥ 500 cows forestripped during their milking routine as opposed to 66% in herds with < 500 cows. However, this qualitative information was self-reported by the dairy producers and TS for each herd of the entire milking routine was not measured. Likewise, in a survey of nearly 1,200 herds across Canada (Belage et al., 2017), 82% and 84% of herds forestripped and dried udders before milking, respectively. There was no difference in these milking practices relative to herd size, however, the categories for herd size were < 37, 37 to 80, and > 80 cows, and the third quartile of herds had 80 cows. Thus, the use of hired labor was likely to be very different between the Canadian and our study.

The sample size of cows within each herd depended on herd size, milking shift length, and cow throughput while milking. In smaller herds, (milking shifts less than four hours) we were present throughout the entire milking. However, especially in larger herds, it was difficult to evaluate all employees and all milking groups of cows across all shifts. Thus, in herds with short intervals between milking shifts, we recorded milking events in portions of two consecutive shifts to gain a wider perspective of milking behaviors. Additionally, we decided to include as our dependent variable only the actual time of tactile stimulation and not the total time of the premilking routine. Anecdotally, w Also, milking routines were often disrupted because of washing clusters or parlor platforms, acquiring clean towels from laundry bins, gathering cows from holding pens, reattaching or adjusting units on cows throughout the parlor, and filling teat dip applicators. Thus, there is no assurance that our observed mean TS for each herd was consistently practiced for every milking string of cows. Likewise, as previously suggested by Wagner and Ruegg (2002), it is difficult to know the contribution of premilking germicide application on milk ejection, as opposed to true tactile stimulation. However, all of our herds applied a premilking germicide by either spraying, dipping, or foaming. Thus, due to the universal nature of this procedure, our study focused on tactile stimulation. To this end, we found considerable variation (2s to 41s) between herds, as opposed to a higher degree of consistency with germicide application and lag times.

Summary

Smaller herd size, fewer passes to each cow in the premilking routine and greater lag times are associated with increasing TS in dairy herds. Variables such as greater shift length and the number of cows milked per hour may also impact TS but are confounded by herd size. Thus, a milking culture that emphasizes milking efficiency rather than parlor efficiency may lead to better premilking stimulation. With increasing consolidation of the dairy industry, milking routines should be evaluated to determine if adequate TS is practiced to help maintain teat and udder health.

Acknowledgements

This project was supported by Agriculture and Food Research Initiative Competitive Grant no. 2013-68004-20439 from the USDA National Institute of Food and Agriculture.

APPENDICES

Appendix A. Tables

Table 5. Bivariate analysis results for explanatory variables of mean total stimulation time in the premilking routine in 64 Michigan dairy herds

Variable	P-value
Herd size (natural log transformation)	<.0001
Number of milking units	<.0001
24 h milk production (kgs)	<.0001
Time of milking system operation (natural log, h/day)	0.0002
Shift length (h)	<.0001
Break length for employees during shift (min)	0.0142
Number of milking units	<.0001
Cows milked per hour (natural log)	<.0001
Number of cows prepped/ h per operator	0.0012
Mean lag time (min)	0.0008
Mean illumination in milking workspace (candela)	0.0418
Rail height in parlor (natural log, cm)	0.1217
Number of passes in preparation routine	0.0022

Table 6. Final linear model for associations between mean total stimulation time during the premilking routine and herd-level variables in 64 Michigan dairies (herd size included)

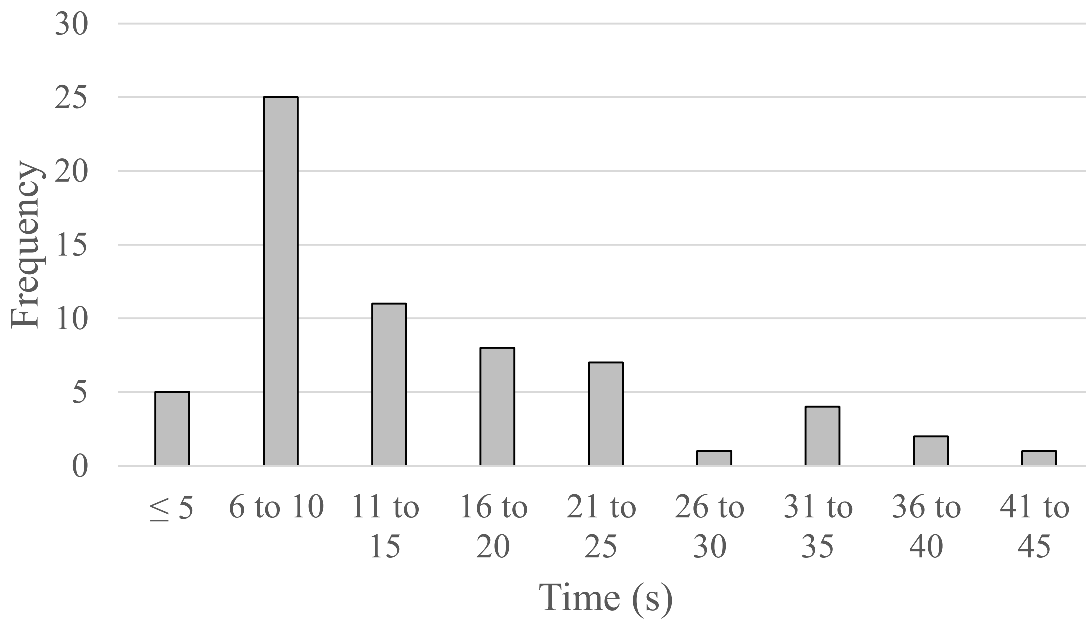
Parameter	Estimate	SE	P-value	R^2
Intercept	4.43	0.56	<.0001	0.58
Herd Size (natural log)	-0.31	0.11	0.0093	
Mean lagtime (s)	0.008	0.002	0.0001	
Number of passes	-0.30	0.08	0.0003	

Table 7. Comparison of means for eligible independent variables for multivariable model between small (<300 cows) and large herds (≥ 300 cows) in 64 Michigan dairy herds

Variable	Small herds mean (SEM)	Large herds mean (SEM)	P-value
Mean total stimulation time (s, natural log)	2.82 (0.10)	2.16 (0.09)	<.05
Mean lag time (s)	110.0 (5.7)	96.9 (4.7)	0.08
Number of passes	2.70 (0.13)	2.65 (0.13)	0.78

Appendix B. Figures

Figure 3. Histogram of mean total stimulation time (s) for 64 Michigan dairy herds.



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CHAPTER 4

OVERMILKING IN MICHIGAN DAIRY HERDS

Herd level variables associated with overmilking in Michigan dairy herds

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Abstract

The objective of this study was to determine the herd level variables that were associated with overmilking in 64 Michigan dairy herds. Mean herd size was 451 cows (range 59 to 2,771 cows and three month DHI geometric mean SCC was 136,795 cells/mL. For each herd, surveys were administered to the producers to gather mastitis management practices and attitudes. Additionally, milking protocols were observed and milk flow dynamics were determined by use of digital vacuum recorders. Milk flow dynamics were recorded for a total of 3,824 cows throughout the study, with a mean of 60 cows per herd (range of 11 to 154 cows per herd). Backwards multivariate analysis was used to determine which of 45 herd-level milking and management variables were associated with median duration of overmilking. Across all herds, median duration of overmilking was 56 s (range of 14 to 172 s) and was negatively associated with the duration of each milking shift ($R_{adj}^2 = 0.13$). The percent of cows in each herd that were overmilked from reattachment of milking units after cessation of milk letdown was not correlated to the median time of overmilking. Given the low coefficient of determination, unaccounted variables, such as equipment function or manual detachment on the part of milking operators, may play an important role in overmilking in addition to longer time intervals between milking shifts.

Key words: overmilking, milking protocols, employee management

Introduction

Overmilking (**OM**) is defined as when milk flow to the teat cistern is less than the flow out of the teat canal (Rasmussen, 2004). This can be caused by improper settings for automatic cluster detachers (**ACD**) that remove clusters after a prolonged period of low milk flow, or by subjective manual removal of clusters by milking personnel. Overmilking results in longer milking times (duration of time that milking clusters are attached to the udder), and thus greater exposure of teat ends to high vacuum levels. In the short term, this can result in congestion within the teat wall, with subsequent damage and swelling of the teat canal (Mein, 2001). This also impedes efficient milk flow, and if the exposure to excessive vacuum from OM continues, teat-end condition can be compromised (Neijenhuis et al., 2000; Mein, 2001; Edwards et al., 2013). Moderate and severely hyperkeratotic teat ends have a higher risk of clinical mastitis than normal teats ends (Neijenhuis et al., 2001; Breen et al., 2009; Paduch et al., 2012). Tančin et al. (2007) reported that quarters with high SCC (> 500 x 10^3 cells/mL) had longer OM phases of milk flow as compared with quarters with low SCC (< 200 x 10^3 cells/mL).

Despite knowledge of the deleterious effects of OM, and milking machine factors that may contribute to OM, little is known of herd level milking behaviors and labor factors that may be associated with the frequency of OM. Additionally, as herd size increases in the U.S. dairy industry, farms are increasingly reliant on hired labor (Baker and Chappelle, 2012; von Keyserlingk et al., 2013) and the impact that the labor culture may have on OM is largely unknown. The objective of this study was to determine the herd level variables, including the labor culture, that were associated with OM in 64 Michigan dairy herds.

Materials and Methods

Dairy Farm Selection

This study was part of a larger project in which 124 dairy herds in Florida, Michigan, and Pennsylvania participated in an 18-month trial to develop an evaluation to assess mastitis and antimicrobial drug use. Sixty-four Michigan dairy herds were visited by the investigators twice between January, 2016 and May, 2017. Enrolled herds participated in the Dairy Herd Improvement (**DHI**) individual cow somatic cell count (**SCC**) option and had a herd size ≥ 70 cows. Because the overall objectives of the umbrella project included employee-related factors on milk quality and antimicrobial use on dairy farms, organic dairies and herds that milked with automated milking systems were excluded. All survey information was collected following approval and performed within the guidelines set by the Institutional Review Board of Michigan State University.

Herd Profile and Management Culture

During the initial herd visit, project investigators explained the study design and conducted a herd profile to record milking times and groups, type of milking facility, housing, employee structure, and other general information. Within 30 to 60 d, the investigators returned to conduct a milk quality evaluation that included 1) milking behaviors and proficiency, 2) milking systems, 3) cow environment, 4) monitoring and therapy of infected cows, and 5) farm management culture. To capture information relative to the management culture, we interviewed dairy producers and/or managers with an 84 question survey relative to their mastitis control practices, attitudes and behaviors (Schewe et al., 2015). Additionally, a separate 16 question human resources survey was administered to describe producer/manager beliefs and practices regarding employee communication, training and education. Approximately 90 minutes was needed to conduct the surveys and review the project with each producer.

Milk Vacuum Dynamics and Analysis

While assessing milking behaviors, we evaluated milking vacuum from 3,824 cows (mean of 60 ± 29 recordings per herd) with VaDia® digital recorders (Biocontrol, Rakkestad, Norway). Four vacuum channels were employed for each individual cow evaluation by attaching 2.4 mm (internal diameter) silicon tubing to record vacuum on the following positions of the milking cluster: 1) rear quarter liner mouthpiece chamber (**MPC**), 2) front quarter MPC, 3) short milk tube (**SMT**) as an estimate for cluster vacuum, and 4) a short pulsation tube. Previous recordings from 40 cows had demonstrated the consistency between vacuum recordings in the short milk tube and actual cluster vacuum by insertion of a needle into the bowl of the cluster (Erskine, not reported).

Each cow-milking event was continuously recorded from the time that milking clusters were attached until clusters were removed, either automatically by milk flow sensors or manually by employees. We employed the four phases of flow intensity: incline, plateau, decline, and OM as described by Tančin et al. (2007) for our intrepretive guidelines and determined the following phases for our study, start of milking, start of the incline phase of milk flow, start of OM (end of the decline phase and near static levels in the SMT and MPC vacuum), and end of milking. All vacuum recordings were downloaded and then reviewed using the VaDia Suite software (Biocontrol, Rakkestad, Norway). Previous research has suggested that milk flow is the inverse of vacuum levels in the cluster (Schukken, 2005). Additionally, Penry et al. (2018) determined that increasing MPC acts to increase teat-end congestion and reduce milk flow rates, i.e., higher MPC vacuum is associated with lower milk flow.

We employed the same interpretation and analysis of milk flow dynamics as previously described (Moore-Foster et al., 2018). For each cow, the start of the incline phase was marked when the vacuum level in at least one of the two MPC channels decreased to < 13.5 kpa (4 inHg) and the SMT vacuum decreased from maximum and fluctuated from 3.4 to 10.2 kpa. Overmilking was determined to begin when MPC vacuum increased and reached a plateau above 13.5 kpa in both channels and the range of SMT vacuum fluctuations narrowed to < 3 kpa. The end of milking was determined to occur when vacuum returned to 0 kpa. (example of VaDia recording, Figure 1).

During the vacuum analysis, the quality of air hoses, liner alignment, and air vent patency were also recorded. Additionally, we observed milking procedures and protocols to determine the milking routine, the time interval between each preparation step and cluster attachment (lag time) and time spent stimulating the teats. A minimum of four milking strings were recorded during milking preparation in parlors. In platform or tie stall milking operations, stimulation and lag times were recorded for at least four cows per cluster. When there was more than one person milking, milking behaviors were observed for a minimum of two milking strings for each person.

Parlor Ergonomics

Measures of parlor ergonomics were estimated by determining the width of the parlor workspace, the height from the floor to the platform, light availability, duration of a milking shift, and the availability of breaks during the shift. Illumination of the milking workspace was measured with a light meter, both in the middle of the parlor floor (mean of three separate locations) and at the level of the teat, under the cow (mean of six to ten locations, depending on the number of milking units). Additionally, we measured the length of the milk space floor to derive an estimate of the minimum linear distance that each person milking cows might travel during a milking shift. The formula to calculate this distance was previously described (Moore-Foster et al., 2018).

Statistical Analysis

Dependent Variable

The dependent variable for this study was the median duration of OM for cows in each herd, as determined by VaDia analysis. Median OM was selected as our outcome variable rather than mean OM after reviewing the skewed distribution of the time period of OM for all the cows included in the study (Figure 2). All data was entered into Microsoft Excel (Microsoft Corp., Redmond, WA, USA) for data management and imported into SAS (ver. 9.4; SAS Institute, 2012) for descriptive and analytical statistical analyses.

Independent Variables

The independent variables were divided into three categories 1) management culture and human resources, 2) employee behaviors and 3) parlor factors. Management culture and human resource variables include milking operator turnover rates (defined as number of operators hired per year divided by number of positions available), as well as survey questions that include frequency of employee training, manager attitudes about parlor turnover rates and how often managers communicate with employees on personal matters. The average pay rate, and if applicable, other benefits are also included. Operator behaviors included total stimulation time, lag time, distance traveled per shift, number of stalls per pass and the proportion of cows-milkings within each herd that had units reattached after milking was finished (as determined by VaDia analysis). Parlor factors include rail height, illumination, how many times cows are milked per day, and if 95% of liners are properly aligned (yes = 1, no = 0) led and if 95% of air vents on the cluster are open (yes = 1, no = 0).

Scale Factor Analysis

Initially a frequency distribution was set up for each independent variable in our model and normality was checked. Scales were tested, accounting for management attitudes and beliefs regarding labor. However, alpha and Eigenvalues were not significant (Eigenvalue >1 and Chronbach's α >0.7) for all of the scales.

Bivariate Analysis

Continuous independent variables that were right skewed were log-transformed before bivariate analysis to attain normality. To decide which independent variables should be included in the model for multivariate analysis, associations between the median OM and explanatory continuous variables were investigated using Pearson's product moment correlation coefficient using SAS (ver. 9.4; SAS Institute, 2012). For binary (nominal) variables, the dependent variable was compared to the independent variables using an Adjusted Wald test for the significance of the relationship. Any variables with an initial cutoff of $P < 0.20$ (2-tails) were considered eligible for inclusion in the multivariable model.

Multiple Linear Regression

Using multiple regression and the type-III F-test, an automated backwards-stepwise elimination procedure was used to build the final multivariable model until only significant covariates ($P < 0.05$) were retained. Interactions were also analyzed, however no significance was found. The residual distribution was assessed visually for normality and homoscedasticity.

Results

The mean herd size was 451 (median: 294) milking cows, ranging from 59 to 2,771 cows (Table 1). 97% (62/64) of surveyed herds milked with ACD. The three-month DHI geometric mean SCC was 136,795 cells/mL and 62/64 herds (97%) reported using hired labor. The mean percent of milking cows digitally evaluated for vacuum dynamics in each herd was 23.5%. The median duration of OM was 47s (95% CI: 38.6s to 55.9s) with a mean of 55% (95% CI: 49.5% to 61.1%) of cows within each herd overmilked by at least 30 s. Median milking time for all herds was 324 s (Table 1; 95% CI: 302, 346) and was found to be positively correlated with median OM (r = 0.670; Figure 3).

Based on bivariable analysis, 25 variables were significant at $P < 0.20$, however ten variables with the lowest P-values and deemed the most significant by investigators were chosen for explanatory variables for multivariable analysis based on the following categories (Table 8): 1) herd characteristics including number of times milking per day, kgs of milk produced daily and herd size 2) employee characteristics including employee turnover rates, shift length, break length, total distance each employee covers during a milking shift, 3) parlor characteristics including hours the parlor is in operation a day, if 95% of vents are clear on milking units, 4) and consistency of pre-milking behaviors within each herd, as measured by the standard deviation of time of teat stimulation at first touch between cows.

Using backward stepwise regression, the final multivariable model found shift length to be negatively associated with median OM (Table 9). Thus for every 0.04 hour (2.4 min) decrease in shift length decrease there is a one second increase in median OM time.

Discussion and Conclusions

The impact of OM on teat end health and congestion was visually described nearly a quarter of a century ago (Shearn and Hillerton, 1996). In our study, median OM time across all herds was > 45 s. This indicates that many herds have an opportunity to increase milking efficiency and enhance cow health, not only by improving teat heath and reducing mastitis (Neijenhuis et al., 2001; Breen et al., 2009; Paduch et al., 2012), but also by decreasing the duration of time for cows within the holding pen or milking area. In our study, MPC vacuum during the OM period was typically > 27 kPa, or more than twice that of what is considered desirable for teat health (Mein, 2001). Penry et al. (2018) found that high MPC vacuum is highly correlated with lower teat canal cross sectional area, which in turn indicates increased teat congestion. Thus, OM can lead to congestion within the teat wall, with subsequent damage and swelling of the teat canal (Mein, 2001). During the massage phase of the pulsation cycle, the compressive load of the liners facilitates venous flow and removal of interstitial fluid (Paulrud, 2005). However, during periods when the milk flow is low or absent, removal of blood and interstitial fluids may be insufficient so that congestion and edema occur (Paulrud, 2005). Thus, our study suggests that a high proportion of a dairy herds may be susceptible to deleterious effects of teat congestion as a result of OM. This was striking because the mean SCC in our study herds was < 150,000 cells/mL

Our results determined that as the duration of milking shifts decrease within herds, the frequency of OM increases. This seems to be a paradoxical result, as observed from our data, herds with greater median OM periods were more likely to have longer milking times per cow. This could lead to slower cow flow through the parlor, longer waiting times in the holding pens, and thus longer shift lengths. However, the negative association between shift length and median OM time in our results could suggest the relationship between milking time, OM, and shift length maybe more complex. OM may occur if automatic detachers are not properly maintained or detachment is set to milk cows too dry. 78% of the herds in this study stated that they have a protocol or schedule for milking equipment maintenance and 83% of the herds evaluate their entire milking system at least once a year. However, many routine equipment maintenance programs do not include ACD service, nor did we assess detacher performance.

From a behavioral perspective, the increased risk of OM could reflect an attitude among operators who work within the labor culture of shorter milking shifts; there may be less pressure to finish milking before the next milking shift begins. Herds that do not emphasize parlor turnover as a crucial management goal may also inadvertently allow employees to have more time to observe cows and subjectively assess if milk is still present in the udder, and consequently make the mistaken decision to continue milking. Our study tried included a survey question asking producers to score the importance of improving parlor turnover rates. However, this question did not reach the bivariate cut off to be included as an explanatory variable in the multivariate analysis. Our results were in agreement with an Irish study (O'Brien et al., 2012) that found as parlor size (number of units) increases, operator idle time decreases. Conversely, when ACD were not in use, OM increased when the number of units per operator increased, which suggests that OM can occur when operators are milking under pressure for greater cow flow (O'Brien et al., 2012). However, except for two herds that milked in a tie-stall barn, all of our study herds had ACD. Overmilking can also occur from reattaching already removed clusters after cows are completely milked. We found no association between the percent of cows that were reattached and median OM time. Anecdotally, some herd managers also suggested that employees, who are were all paid by the hour in this study, might be financially incentivized to milk cows a little longer, thus reducing the parlor flow and increasing the shift length and pay.

Although individual cow variables were not measured in this study, Tančin et al. (2007) reported that bimodal milk ejection and SCC were associated with increased duration of overmilking. We did not find this association between delayed milk ejection and OM in our study. This may be due to other cow factors that were not measured in our research. Indeed, Sandrucci et al (2007) found that as farm size increases, less time is spent on proper teat stimulation, therefore reducing time for udder preparation. In a previous study, we determined that less teat stimulation was associated with increased bimodal milking (Moore-Foster et al., 2018). Taken together, an intriguing dynamic that suggests as herds try to increase parlor throughput, less preparation is given to each cow, resulting in more bimodal milking, but herds that "take their time" to effectively prepare udders before milking may be more susceptible to OM. Both of these potential problems with milking efficiency are often related to operator behaviors. Thus, with the increasing reliance on hired labor in the dairy industry and the lack of capacity on many farms to effectively train employees, more research and programs to train and educate employees on dairy farms may be beneficial (Bewley et al., 2001).

There were several limitations in this study. We used vacuum as a qualitative, not quantitative measure of milk flow. Recording flaws (i.e. disconnected tubes, failed batteries on the VaDia recorders) resulted in less than 5% of the recordings, but this data could not be assessed for the occurrence of OM and was thus excluded. The sample size of recorded cows within each herd varied depending on herd size, the duration of the milking shift, and the time period that we were present for the parlor evaluation. In smaller herds, (milking shifts less than four hours) we were present throughout the entire milking. However, it was difficult to evaluate all employees, and milking groups for all shifts, which was especially true in larger herds. Thus, in these herds, we recorded milking events in portions of at least two shifts and several milking groups to serve as indicators for the entire herd. Also, we placed multiple VaDia units at diverse milking positions in a parlor to capture as much variation as possible relative to lag time and individual employees/producers. Additionally, numerous individual cow factors such stage of lactation, genetics, teat anatomy and parity could play a role in milk flow and the propensity to overmilk, which were not accounted for in our study.

Summary

Decreasing shift length is associated with increasing OM times in dairy herds. Thus, management factors that result in more relaxed parlor flow may lead to greater subjective determination of completion of milking in cows, which may decrease milking and parlor efficiency. In these herds, it is important to assure that detaching equipment is well maintained and milking operators are trained to either better determine when milking is complete or rely on ATD.

Acknowledgements

This project was supported by Agriculture and Food Research Initiative Competitive Grant no. 2013-68004-20439 from the USDA National Institute of Food and Agriculture.

APPENDICES

Appendix A. Tables

Table 8. Bivariate analysis results for explanatory variables of herd-level median duration of overmilking in 64 Michigan dairy herds

Variable	P-value
Herd size (natural log transformation)	0.12
Shift length (hours)	0.0035
Employee break length (min)	0.13
Number of times milking per day	0.03
Milk produced in 24 hrs (kgs)	0.02
Total distance employees traveled during a shift (natural log, meters)	0.03
Hours milking per day (natural log)	0.08
Employee turnover in 12 months	0.19
Are 95% of vents open on milking units?	0.03
Variability of stimulation at first touch	0.16

Table 9. Final linear model for associations between median overmilking time and herd-level variables in 64 Michigan dairies

Parameter	Estimate	SE	P-value	R^2
Intercept	1.78	0.08	<.0001	0.13
Shift length (h)	-0.04	0.01	0.0035	

Appendix B. Figures

Figure 4. Example of digital vacuum recording demonstrating overmilking. The vertical axis indicates vacuum (kPa). . The horizontal axis indicates time after cluster attachment divided into 15 s intervals. Channels 1 and 2 (white arrow) represent the rear and front mouthpiece chambers, and channel 3 (black arrow) the short milk tube as a proxy for cluster vacuum. Symbols mark the start of milking (◊), start of overmilking (▲) and end of milking (Δ).

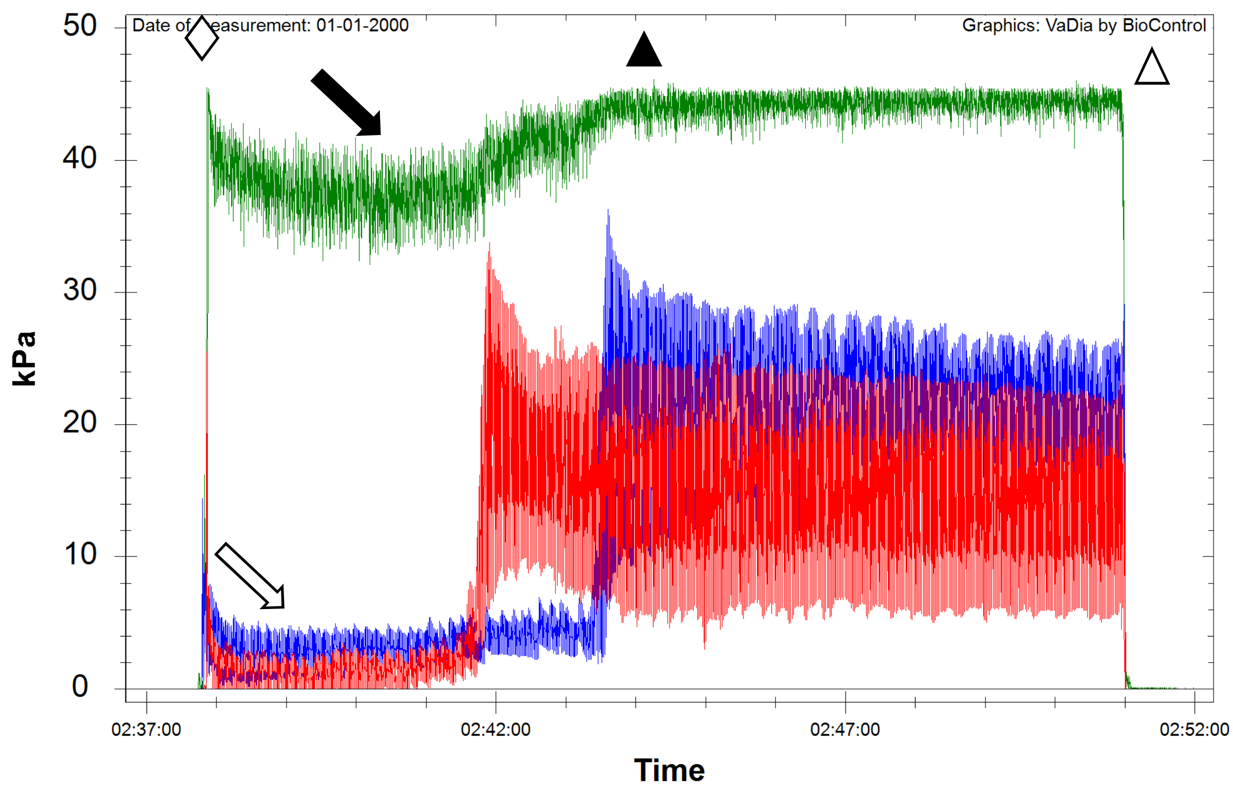


Figure 5. Histogram of duration of overmilking (s) of individual animals in 64 Michigan dairy herds as recorded by digital vacuum (n=3,824 cows)

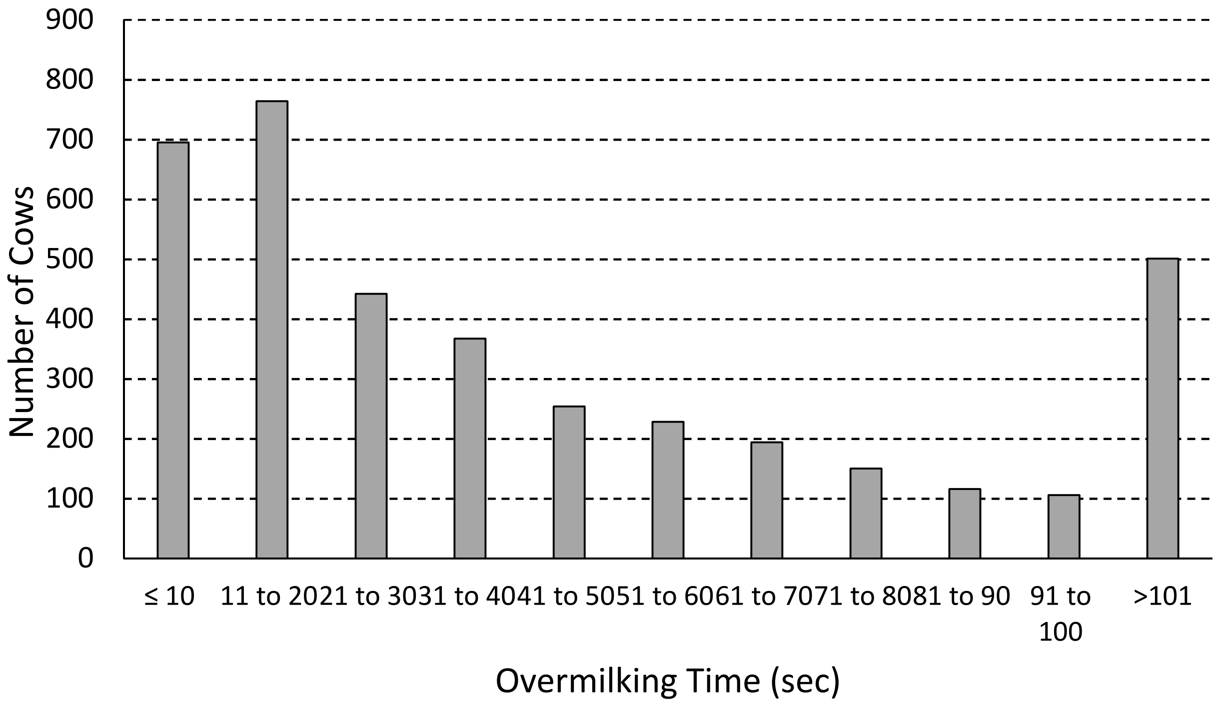
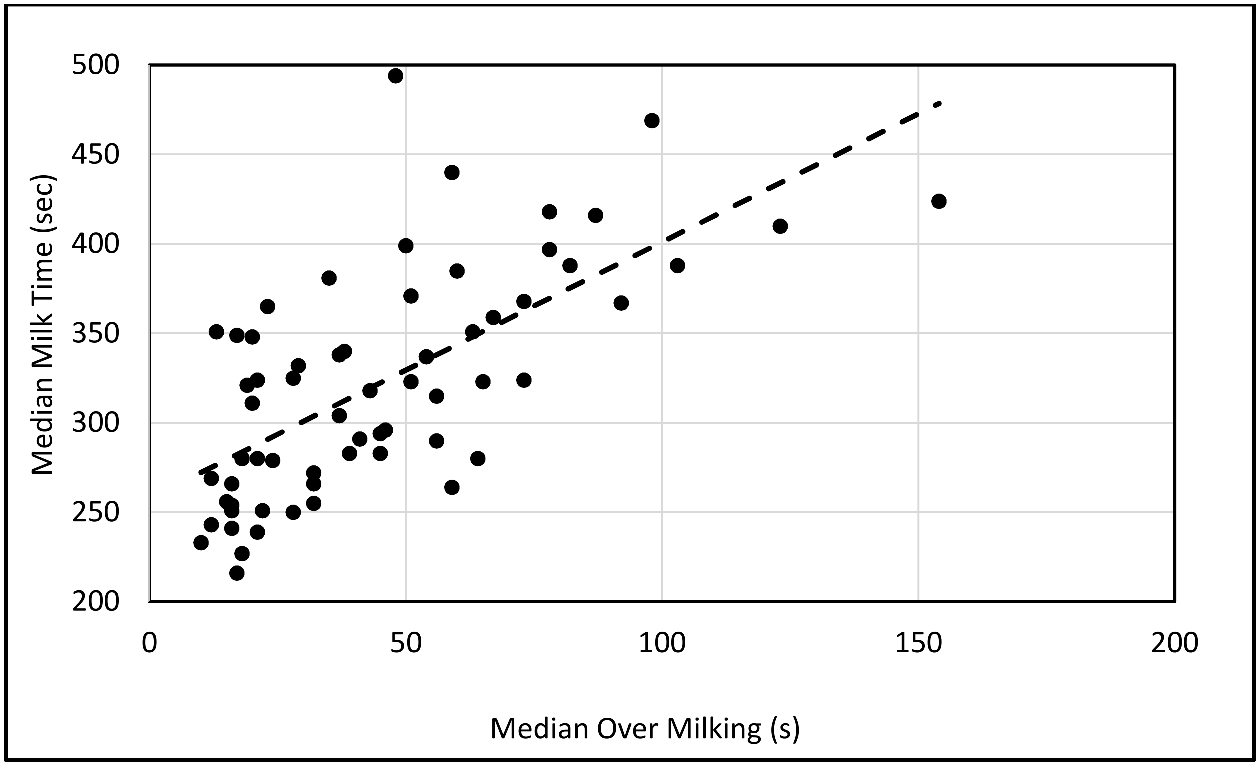


Figure 6. Correlation of median overmilking time (s) on horizontal axis vs. median unit on time by herd on the vertical axis (n=64)



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CHAPTER 5 CONCLUSION

The dairy industry is changing and with those changes there is an increasing reliance on non-family labor. The growing employee force desire training and educational opportunities, however more importantly, they are wanting the scientific knowledge explaining why protocols are important. The actions of employees have a direct impact on milking outcomes including delayed milk ejection, stimulation time during the pre-milking routine and overmilking. This dissertation identified some of the employee, management and parlor variables that explained these outcomes.

.... In chapter 2 stimulation time during the pre-milking routine proved to be a significant independent variable effecting the herd-level prevalence of delayed milk ejection. However, little research has shown what employee factors affect stimulation time. Chapter 3 investigated this question with the multivariable model showing that stimulation time was associated with number of passes in the pre-milking routine. Increasing herd size being associated with decreasing stimulation time and because of this relationship, increased risk for delayed milk ejection. Both of these results suggest that larger herds, which tend to emphasize parlor efficiency may have less focus on ensuring an adequate parlor routine, thus driving employees to milk cows faster at the expense of stimulation.

Chapter 4 investigated what independent factors were associated with overmilking. Multivariable analysis showed that shorter shift lengths were associated with increased overmilking time. This characterizes issues that are typical of smaller herds, with shorter shift lengths, employees feel less 'parlor push' pressure and therefore have more time to subjectively decide if cows have completed milking. These employees may be more prone to reattaching milking units or setting them to manual in an attempt to harvest more milk.

In both of these scenarios, employees play a crucial role in a cow's ability to have a quick, efficient, and comfortable milking experience. With the current changes in the dairy industry, those employees deserve opportunities for training as well as pathways for communication with management and especially herd veterinarians, which may retain educated, engaged employees on farms. However, this is only the start and further research is needed to investigate what management characteristics may be associated with such variables as employee turnover and performance independent of herd size.