

Housing, Management and Factors Associated with Efficiency of Automatic
Milking Systems on Midwest U.S. Dairy Farms

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Justin M. Siewert

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Chapter 1

Literature Review

INTRODUCTION

Many of the developments in production agriculture of the 19th and 20th centuries focused on the automation of routine tasks to improve consistency and labor efficiency on farms. This included automated feeding and environmental control for production systems of many livestock species. In the later part of the century, developments had been made to further automate the process of milk collection from dairy cattle. In the 1960's and 70's systems to automatically remove the milking unit at the end of milking were introduced (de Koning, 2010). With installation of the first commercially available fully automatic milking system on a farm in 1992 in the Netherlands, automation of teat preparation and milking unit attachment had been accomplished. Since that time many refinements of the automatic milking system (**AMS**) technology and management have been made to make automatic milking a viable system for many dairy producers throughout the world.

IMPLEMENTATION OF AMS

AMS Adoption

Producers choose to adopt AMS for a variety of reasons; however, by far the most common and important factor for most dairy producers relates to both the social and economic aspects of labor. This was a main driving factor influencing the initial development of AMS and was reported in a survey of dairy producers who had implemented AMS conducted by de Jong et al. (2003) to be influential in their consideration of automatic milking. For many smaller farms, this means improved flexibility of their schedule and a reduction in the physical intensity of labor, most if not all of which, is provided by the family owning the farm. For larger farms, AMS may be a means to reduce hired labor and to provide an improved quality of life to the employees they do hire. de Jong et al. (2003) surveyed North American dairy producers that were using AMS and reported that 84% of them cited having a more flexible work schedule as a reason for making the decision to install AMS. Interestingly however, farmers did not report a reduction in hours of work on the farm but they did have a reduction in physical labor; in addition, 70% of the farms reported decreased cost of hired labor.

By mid-2011 it was estimated over 11,000 farms worldwide had implemented AMS with the greatest adoption rates coming from the region of northwestern Europe (de Koning, 2011). At that time, more than 90% of the AMS in the world were located in northwestern Europe. The Netherlands was home to 2,300 farms using AMS, the most of

any country. Just a few years later, Barkema et al. (2015) reported over 25,000 dairy farms had implemented AMS worldwide.

A few factors have likely driven these differences in adoption rates of automatic milking throughout the world. AMS were first available in the Netherlands and spread throughout the world from there, with very slow adoption until the late 1990's (de Koning, 2011). The northwestern region of Europe has experienced relatively higher labor costs and a shortage of available labor for farm work compared to the United States, making AMS more economically appealing. These farmers also faced decreasing milk prices, necessitating an increase in productivity per man-hour (de Koning and van de Vorst, 2002). Also, until mid-2015, dairy farmers in member countries of the European Union operated under a quota system that had been set up in 1984. This inhibited farmers from increasing milk output without purchasing additional quota. Because of the quota system, farmers had the choice of either purchasing additional quota to expand or improve efficiency of milk production from each cow, therefore producing the same amount of milk with fewer cows, less feed, and other expenses (Rotz, 2003). Canada's dairy producers face a similar situation as European farmers did, with a quota system that continues to be in place and labor that is less affordable than what the United States has experienced. Because of the Canadian dairy situation, Rodenburg (2008) reported the average Ontario dairy herd to be 70 cows and most herds milking twice a day. The United States dairy industry operates in the free market without quotas, has more larger

dairies (500 to thousands of cows) especially in the central and western parts of the country, and has more affordable labor available (de Koning, 2004). The economics of AMS has been favoring smaller producers (about 60 to 240 cows) thus far, therefore being best suited to meet the demands of Canadian dairy producers in the North American market.

AMS were not available in the United States until 2000, later than they were in other parts of the world. A survey of small to mid-sized dairy farms (50 to 280 cows) in Maryland and Pennsylvania found investments in improving their dairy operations is inhibited by low profits, the cost of land, and availability of labor (Moyes et al., 2014). Of these, issues with labor availability and profitability could potentially be addressed with the implementation of AMS. While adoption has been slow, 38% of respondents stated they were at least slightly interested in AMS technology for their farm. Higher level of education and larger farm size were associated with greater interest in AMS. The survey also found profitability and changes in management were two of the greatest areas of concern; while improved herd management and management of time for family were major factors influencing interest toward AMS.

The USDA-ERS (MacDonald et al., 2016) reported the average dairy herd size in the United States in 2012 was 144 cows. However, a more accurate depiction of herd size in which cows are located can be found by looking at the midpoint herd size, which in 2012

was 900 cows. This is interpreted to mean half of cows in the US are in herds larger than 900 cows, and half in herds smaller than 900 cows. This midpoint herd size has grown at an increasingly rapid rate over the past 30 years, with no indications for slowing in the future. There are signs that larger farms will adopt AMS, as a few have done so already. Notable recent announcements include TDI Farms in Michigan installing 24 DeLaval VMS units to milk 1,500 cows; and Chilean Dairy, Fundo El Risquillo, installing 64 DeLaval VMS units to milk 4,500 cows. Farms who have transitioned to AMS report changes to type and amount of labor; from the physical work of milking to more management tasks and monitoring of data (de Jong et al., 2003).

Transitioning to AMS

Transitioning a herd to AMS requires not only adapting to a new milking system, but also a new system of management. A study of Finnish dairy farms evaluating farms that transitioned from either tie stalls to loose housing with a conventional milking system, or tie stall facilities or loose housing with a conventional milking system to AMS, found decreased energy corrected milk (ECM) yield during the transition period (Hovinen et al., 2009). This decrease in ECM yield was significantly greater in herds that transitioned to AMS than those to a conventional milking system, with a decrease of 1.4 and 0.2 Kg/d respectively. However, by the end of the first year using the new facility herds in both types of systems were approaching yield levels seen prior to the transition, with AMS managed herds still lagging behind conventionally milked herds. This contradicts the

findings of Rasmussen et al. (2001) and Jacobs and Siegford (2012), where milk yield dropped briefly following the implementation of AMS but quickly recovered and exceeded pre-AMS production levels.

Both Rasmussen et al. (2001) and Hovinen et al. (2009) found negative impacts on udder health in the year following AMS implementation with elevated SCC; however, SCC began to revert back toward pre-AMS levels after the first few months. In a survey conducted by de Jong et al. (2003), about 55% of farms realized a decrease in SCC after transitioning to AMS, 27% reported no change, and 16% experienced an increase in SCC. An association between increased frequency of stall cleaning and reduced SCC in on these farms was also noted. Jacobs and Siegford (2012) also found incidence of urination, defecation, vocalization, and stepping prior to teat cup attachment rapidly decreased following the first day of AMS use, and within a week of AMS implementation, greater than 60% of the herd was voluntarily visiting the AMS.

Depending on the herd, not all cows will successfully transition to the AMS. In a study of udder conformation, Miller et al. (1995) found 13% of first lactation cows were expected to experience attachment failure by the AMS arm, 91% of which was primarily due to rear teats being placed too close together. In third and greater parity cows, 14% were expected to experience milking unit attachment failure, with front teat placement (primarily due to teats placed too far from each other) as the primary risk factor for

attachment failure (78%). Twelve percent of the cows in a research herd transitioning to an AMS facility were found to be unable to adapt to the AMS due to issues with udder conformation (Jacobs and Siegford, 2012). Of the commercial farms surveyed by de Jong et al. (2003), 70% reported having to cull an average of 4% of the herd that were unable to adapt. Citing primarily udder conformation (60% of culls), but also refusal to enter the AMS voluntarily and restlessness in the AMS as common factors making cows unsuitable for automatic milking. These farmers reported older cows had more difficulty adapting to the new system and therefore were more likely to be culled. Because of this, with time the number of cows needing to be culled as a result of failure to adapt to the AMS should decrease.

HOUSING

Facilities and Housing

AMS have been implemented successfully in combination with a variety of different housing systems, including freestall, compost and bedded pack barns, and pasture-based systems. Within these facility types many variations exist in terms of ventilation and heat abatement, lying surface, manure management, lighting, and layout (de Jong et al., 2003; Rodenburg and Wheeler, 2002). Both retrofitted existing facilities and entirely new facilities have been used to install AMS. However, for dairy producers considering retrofitting the AMS into existing facilities, Rodenburg (2010) suggested keeping record of the compromises made when fitting the AMS into those existing facilities, and

compare the cost, compromises, and feasibility of moving forward with the retrofit versus building a new facility.

Recent recommendations for AMS facilities include a large open area in front of the AMS at least 20 feet wide where cows can wait to enter the milking unit. Field observations have found this design, rather than older layouts that funneled cows toward the AMS, allows for cows to be more comfortable coming to be milked voluntarily, especially timid cows (Rodenburg, 2010)

A holding area leading to the AMS is necessary for the efficient fetching of cows. This is a small pen, large enough for 4 to 5 cows per AMS, where fetch cows are placed. The only exit from this pen is through the AMS unit, forcing these cows to be milked. While there are many different ideas concerning holding area design, one such layout is the “split entry” holding area, advocated for by Rodenburg (2010). In this design, fetched cows in the holding pen are given priority to entering the AMS; however, the rest of the herd also has access to the AMS without having to pass through the holding pen, preventing dominant cows from entering the holding pen which could result in the more timid cows having to wait even longer to be milked.

Orientation of the milking unit in the pen has been found to be influential on cow use of the AMS. Among farms that had two AMS units in a single pen, Gelauf et al. (2009) evaluated the cross use and selective use of the cows managed with different AMS unit layouts. Selective use, defined as cows using one of the AMS units $\geq 90\%$ of the time, was lowest when the two milking units were placed in tandem with each other and cows entered the unit from the same side. Selective use was greatest when cows had previously learned to use only one of the AMS units or when the two AMS units were placed head to head, having a right or left entry. Visibility of the pen from the AMS also showed some association with selective and cross use. It appeared cows would more freely use both AMS units when both had good visibility of the pen.

Many farms with AMS have designed the facility to minimize the amount of equipment traffic in the pens required for manure management. A survey by de Jong et al. (2003) of US and Canadian dairies found the majority of farms used automatic scrapers to scrape the manure from pen alleys and an additional 20% of farms used slatted floors.

Rodenburg (2010) also supported this suggestion, since cows never leave the pen, making manual scraping inconvenient and disruptive to the cows. While conducted less frequently than alley scraping, Rodenburg also suggested automatic bedding delivery systems or stall surfaces that require less bedding be evaluated as another way to reduce equipment traffic in the pen. However, if manual scraping is used, the barn should be

designed with adequate cross over alleys, allowing cows to escape from the scraping equipment efficiently and safely (Rodenburg, 2010).

While there are many factors to consider when designing facilities, Rodenburg (2010) recommended dairy producers prioritize ease of handling and moving cows when designing the barn, allowing for one person to do these tasks alone. Properly designed facilities will likely help producers realize the greater labor efficiency expected with the AMS than they will in poorly designed facilities.

Feeding, Feed Bunk Space, and Nutrition Management

Feed bunk space is positively associated with average daily milk yield (Deming et al., 2013). Both milking and delivery of fresh feed are known to stimulate increased feeding behavior, with delivery of fresh feed having a much greater draw for cows to visit the feeding area (DeVries and von Keyserlingk, 2005). However, the potential for reducing feed bunk space in AMS compared to conventional systems has also been discussed by Wagner-Storch and Palmer (2003) due to reduced variability in the percent of cows feeding at one time throughout the day since all cows are not returning from the milking parlor at the same time.

With the combination of two feeding systems with AMS (concentrates fed in the AMS milking station and a partial mixed ration offered at the feed bunk), farms must work to

balance these two work harmoniously. Feeding of concentrate in the AMS stimulated increased frequency of visits to the AMS (Prescott et al., 1998); however, the amount of concentrate offered did not significantly influence the average number of voluntary milking visits per cow per day, or the number of involuntary visits that were the result of being fetched for milking by a farm worker (Bach et al., 2007). Therefore, to minimize the amount of feed left unconsumed during visits to the AMS and to realize the benefits of precision feeding, Bach and Cabrera (2017) suggested concentrate allotment to be limited to less than 4 kg/d and 1.5 kg/visit.

Madsen et al. (2010) evaluated how changing the ingredient composition of the concentrate fed in the AMS influenced daily visits to the AMS. Barley and oat based concentrates were consumed at a higher rate and stimulated greater daily visits to the AMS and milk yield, whereas low intake of the artificially dried grass and fat based supplement were observed. However, it is important to note that the nutrient composition was not consistent across these pelleted feeds that were tested. Therefore, as with any feeding system, both palatability and nutrient composition need to be evaluated when developing and comparing concentrate to be fed in the AMS.

Using pelleted feed mix of varying ingredient inclusion rates could be beneficial to more precisely feed individual cows. Halachmi et al. (2006) found both pellets high in starch (higher levels of ground barley, corn, sorghum, and wheat bran) and pellets high in

digestible NDF (higher in soy hulls, corn gluten feed, and soybean meal) can be used successfully to attract cows to the AMS. The two concentrate diets resulted in similar daily milk visits, milk yield, and fat corrected milk yield. This is useful as dairy farmers may wish to feed cows of differing stage of lactation or production level different concentrates to more economically and adequately meet their nutritional needs. This also shows palatability can be maintained when significant changes are made to the nutrient and ingredient composition of the concentrate feed offered.

A challenge for AMS in pasture based systems is the relatively large percentage of cows with long milking intervals (defined as greater than 16 hours). Lyons et al. (2013) found 46.9% and 38.0% of milking intervals exceeded the 16 hour threshold in groups of cows fed a partial mixed ration and concentrate pre vs. post milking, respectively. Davis et al. (2005) also reported a low milking frequency in a pasture based system with an average of 1.13 milkings per day (range of 0.9 to 1.9). These milking frequencies are considerably lower (and therefore milking intervals are considerably longer) than the 4.2% of milking intervals exceeding 16 hours in conventional housing systems with AMS milking (Hogeveen et al., 2001).

Lyons et al. (2013) found differences in cow behavior when comparing supplementation before vs. after entering the milking unit (robotic rotary parlor) in AMS pasture systems. Cows returned from pasture to the milking barn sooner (11.9 vs. 13.3 hours for groups

fed pre or post milking respectively); however, cows fed before milking spent more time in the feeding and waiting areas before entering onto the AMS platform, resulting in a decreased average milking frequency compared to those fed post milking (1.58 vs. 1.67 milkings per day for groups fed pre and post milking respectively). It is important to note that while there were differences in cow behavior, no differences were found in daily milk yield between the two feeding management systems.

Cow Traffic Flow

Cow traffic pattern has been of interest and debate in the AMS industry. The primary traffic systems used are “free flow” and “guided flow,” with various modifications of these systems used to a lesser extent on farms and in research. “Free flow” traffic, where cows have unrestricted access to the feeding area, lying area, and AMS unit, have been shown to be associated with greater milk yield per cow per day (Tremblay et al., 2016). In “guided flow,” also sometimes described as “forced flow” traffic designs, cows must visit areas of the barn in sequence, such as from the lying area to the feeding area to the AMS unit, or lying area to the AMS unit to the feeding area. Guided flow has been associated with increased number of milkings per day and reduced number of cows being overdue for milking and needing fetched (Bach et al., 2009). Cows managed in guided flow systems have also been shown to consume fewer meals per day but also have larger meals and longer meal duration when they do visit the feed bunk, resulting in no difference in total eating time, eating rate, or average daily DMI (Bach et al., 2009). In a

study of guided flow vs. semi-guided flow traffic designs, Hermans et al. (2003) found no differences in number of cows needing to be fetched or in average number of milking visits per day, but did find cows managed in a semi-guided flow system spent more time eating and less time standing in the free stalls than when subjected to guided flow pen design. Munksgaard et al. (2011) compared free and guided flow systems and found no differences in the number of cows needing to be fetched for milking between the systems, but cows in the free flow system did make more visits per day to the feeding area. However, the AMS were not used to capacity, with 35 cows per AMS, which may have impacted these results. Westin et al. (2016) found no association between lameness prevalence and traffic type.

MILK YIELD AND AMS VISITS

Milking Frequency and Efficiency of Milk Yield

Due to the voluntary nature of the AMS, and the desire by cows to visit the AMS for milking and to receive concentrate (Prescott et al., 1998), increased milking frequency above the typical twice daily milking in conventional systems can be achieved without the need for additional labor and potentially a reduction in labor (Dijkhuizen et al., 1997).

Milking interval is of interest as it has been widely studied to have a positive association with milk yield, both within AMS and in conventional milking systems. Three times per

day milking in conventional milking systems was associated with 3.5 Kg/d increased milk yield and 92 g/d increase in milk fat yield when compared to twice daily milking (Erdman and Varner, 1995). Increased milking frequency (4 times daily versus 2 times daily) during the first 3 weeks of lactation in a conventional milking system resulted in greater milk yield that was sustained beyond the early stage of lactation (Hale et al., 2003). Milking frequency has been shown to have a positive association with productivity in AMS, with a greater effect in higher producing cows than those who are lower producers (Hogeveen et al., 2001). Wagner-Storch and Palmer (2003) found increased daily milk yield in AMS compared to a conventional milking parlor with twice daily milking, which they largely attributed to increased milking frequency.

Unlike conventional milking systems where cows experience relatively consistent milking intervals, AMS herds have much more variation in milking interval as cows choose when to be milked (Hogeveen et al., 2001). This provides both challenges and opportunities. A major factor reported for the implementation of AMS is to increase milk yield by increasing the milking frequency and therefore decreasing the average milking interval. In a survey by de Jong et al. (2003) and the study conducted by Hogeveen et al. (2001) herds milked with AMS averaged 2.6 milkings per day with well managed herds (Rotz, 2003) and Ontario, Canada herds (Deming et al., 2013) achieving 2.8 milking per day. These milking frequencies are within the normal range of 2.5 to over 3.0 milkings per day experienced by most commercial dairy farms utilizing AMS (de Koning, 2010).

It is important to note however, that although the mean milking interval decreases, that will not be true for all cows, as some will have considerably longer milking intervals. A research herd (Hogeveen et al., 2001) using one AMS unit had a mean milking interval of 9.2 hours with a standard deviation of 3.3 hours and a median milking interval of 8 hours. This farm brought cows to the AMS that had not been milked for an unspecified interval two to three times per day, which reduced the variability that would have been experienced if cows of a long interval from previous milking were fetched less times per day.

Milking frequency in AMS (and therefore milking interval) has been reported to be influenced by many factors. Speroni et al. (2006) found milking frequency to be influenced by season, where milkings per day averaged 2.7 in the winter and 2.6 in the summer in an AMS. This study, which compared a conventional milking system and AMS, also found the AMS group had greater losses in milk yield in the summer relative to their winter milk yield (-4.5 vs -3.0 kg/cow/d). Prescott et al. (1998) found cows had a much stronger motivation for eating the concentrate than for milking, indicating the availability of feed in the AMS a necessary component in enticing cows to visit the AMS frequently. However, not only is availability important, but also palatability. Madsen et al. (2010) found palatability was associated with number of daily milking visits, concentrate intake, and milk yield. Milkings per day were negatively associated with

days in milk (DIM), parity, and cows per AMS unit among cows 144 ± 34 DIM (mean \pm SD) (Deming et al., 2013).

Jacobs and Siegford (2012) suggested that adjusting the AMS settings to reduce milking frequency in the week prior to dry off could be used to reduce the milking frequency and therefore milk yield. This is based on the findings of Tucker et al. (2009) that found reduced milking frequency (once per day vs. twice per day) in the week prior to dry off reduced milk yield. This study also found restricted feed intake during the week prior to dry off reduced milk yield and tended to reduce the risk of intramammary infections during the early stages of the dry period. However the benefits of restricted feed intake were countered by increased hunger, determined from the fact these cows vocalized more than the other study groups, resulting in welfare concerns for the cows fed at the reduced rate.

More research should be conducted to evaluate the use of AMS settings to optimize milking interval and restrict concentrate intake in order to reduce milk yield prior to dry off, while minimizing the discomfort of hunger and distension of the udder, potentially through more gradual or cow-specific changes.

Failed Milking Visits

Failed milking visits result when the AMS is unable to attach or reattach the milking unit due to equipment failures, udder conformation that is not suitable for automatic milking, or the cow fails to stand stationary, preventing the robotic arm from finding the teats and attaching the milking unit. A survey of Canadian dairy farms located in Ontario found herds experienced 0 to 3 additional culls per year (mean herd size of 94 cows) due to udder conformation issues, primarily due to rear teats placed too close together or too far back on the quarters (Rodenburg, 2002). Failed milking visits hinder the efficiency of the AMS as cows that experience milking failure are slower to leave the AMS (Stefanowska et al., 1999), and when adjusted to a milk yield per hour basis, leads to reduced milk yield in subsequent milkings in quarters that failed to be successfully milked (Bach and Busto, 2005).

Refused Milking Visits

Refused visits to the AMS result when cows approach the AMS before adequate time has lapsed since the previous milking event. The limits on milking frequency are set in the AMS software by each farm and vary from farm to farm and within farm by stage of lactation and predicted milk yield. King et al. (2017) found refused visits to be negatively associated with the number of cows per AMS. However, a low number of refusals may be indicative of good use of the AMS by cows. Lely

https://www.lely.com/media/filer_public/0a/19/0a19b805-6d5a-4485-9c94-

[e56496598bc7/lily_kennisdocument - management en.pdf](https://www.researchgate.net/publication/312549659/figure/fig/1/figure-fig1/1517218111111/e56496598bc7/lily_kennisdocument_-_management_en.pdf)) recommends having a goal of at least one refusal/cow per d and balancing this goal for having some refused visits to the AMS by maintaining a minimum of 150 min/d of AMS free time where the milking unit is not being used.

WELLBEING, BEHAVIOR AND HERD MANAGEMENT

Lameness

For dairy farms with AMS to be successful, it is essential cows visit the AMS voluntarily. Westin et al. (2016) found a positive correlation between the number of times per day farmers reported fetching cows for milking and the herd level lameness prevalence. King et al. (2017) also found lame cows required fetching for milking more frequently than their herd mates that were not lame, and Bach et al. (2007) found lameness to be associated with reduced daily milking visits to the AMS and reduced milk yield. King et al. (2017) also found lame cows had a lower frequency of refused visits to the AMS than cows that were not lame. The effects were more pronounced in primiparous cows than multiparous cows, which may indicate primiparous cows experience more pain from lameness than their multiparous herd mates. Lameness was also found to be associated with a greater proportion of milking visits resulting from cows being fetched and brought to the AMS manually, rather than the cows visiting voluntarily. This agrees with the findings of Borderas et al. (2008), where among cows classified as high and low visiting frequency to the AMS, there was a lower prevalence of lameness in the high visiting

frequency group than in the low visiting frequency group. Lameness prevalence varies considerably among farms. Herd lameness prevalence ranged from 2.5% to 46% with a mean of 15% on farms using AMS surveyed by Westin et al. (2016). Seventy-seven percent of farms that had transitioned to AMS reported increased ability to detect lameness in AMS and 30% reported increased likelihood of culling lame cows compared to their prior management system (Tse et al., 2017).

Lameness can be influenced by a variety of factors, many of which relate to housing facilities. Narrow stall width, presence of hock and knee lesions, low body condition score, and parity ≥ 2 were associated with increasing odds of lameness (Westin et al., 2016). Housing factors, including a wider feed alley, increased pen space per cow, unrestricted lunge space and bed type (sand vs. all others) were associated with lower odds of being lame.

With the unique challenges caused by lameness in AMS herds, reliable lameness detection methods are necessary to assist dairy producers in identifying lame individuals and providing them the proper care. Scale systems to measure the weight distributed to each leg during the milking process in the AMS unit can be used to show when a cow is restless or when their weight distribution begins to deviate from their baseline weight distribution, indicating that the cow is potentially lame (Pastell et al., 2005). Work has also been conducted to develop other automatic lameness detection systems, including a

system utilizing photographs of back posture (Poursaberi et al., 2010), and a system using a mat that measures dynamic forces placed in an alley where cows walk through that measures the force exerted by each foot as the cow steps on the mat (Pastell et al., 2008).

Cow Behavior

It has commonly been stated by farmers, AMS manufactures, and others working with dairy producers that managing cows in an AMS has benefits to their wellbeing and behavior. This was discussed in an article by Holloway et al. (2014), which interviewed dairy farmers and cited AMS manufactures' literature. Farmers commented the cows were more relaxed and content in their environment after the installation of AMS, as cows are allowed "freedom" to perform their daily routine voluntarily without being forced to leave the pen to attend the milking parlor at specific times. This "freedom" is restricted to the confines of the pen and is managed so cows continue to choose activities that result in desirable outcomes for the dairy producer (frequent visits to the AMS unit for milking).

These beliefs, however, have not been conclusively supported in the literature. Hopster et al. (2002) found marginal to no differences in behavior and indicators of stress between cows milked in an AMS and a conventional milking system. Heart rate was lower in AMS milked cows prior to and at the beginning of milking and had lower adrenaline levels in the early phases of the milking process. Cows milked in the

conventional milking system stepped less frequently during teat preparation for milking but cows milked in the AMS stepped less frequently during teat cup removal. Gyax et al. (2008) found cows milked in AMS exhibited signs of increased stress compared to a conventional milking system, with increased heart rate and more stepping while milking. Cows milked with Lely AMS in a free flow design exhibited signs of less stress than cows milked with DeLaval AMS in a guided flow design (Gyax et al., 2008). Lexer et al. (2009) found no significant differences in indicators of chronic stress between partially guided flow AMS or free flow AMS and a conventional milking system. While cows managed in an AMS facility do not have to spend extended periods of time waiting in the holding pen to be milked, as do cows in conventional milking facilities, cows of lower dominance ranking spend more time standing in the waiting area to enter the AMS than more dominant cows do, and tend to leave the waiting area without being milked more often than higher ranking cows (Ketelaar-de Lauwere et al., 1996). Therefore, an improvement in time budget in AMS facilities compared to conventional systems may not be experienced by all individuals.

Efficient cow flow through the AMS is an important factor influencing the availability of the AMS for milking. This can be inhibited by cows hesitating to leave the AMS, cows remaining in the exit lane, and cows blocking the exit lane outlet. Jacobs et al. (2012) reported that cows exited the AMS slower when they were not milked (sufficient time from the previous milking had not lapsed), compared to cows who were successfully

milked. Cows were more hesitant in the exit lane if another cow was blocking her exit from the lane on the other side of the exit lane one-way gates, or if other cows were in the holding pen at the exit of the AMS. Later lactation and mid lactation cows were also more likely to hesitate in the exit lane than cows in early lactation. Interestingly, primiparous cows were more often the cause of blocking events than multiparous cows. Additionally, lighter primiparous cows were more often the cause of blocking events than heavier primiparous cows.

Herd Monitoring

The approach to monitoring and managing the health of cows, especially udder health and mastitis is different for farms that utilize AMS compared to conventional systems. Since the manual labor of milking is eliminated in AMS systems, so too the manual detection of mastitis during milking. To overcome this, the use of sensors measuring electrical conductivity of the milk, milk color, milk composition, and milk yield are implemented and become critical to efficiently detect mastitis in a timely manner. These sensors, in combination with algorithms that convert the raw data into alerts, placing cows on attention lists for use by the dairy farm workers, are the basis for mastitis detection on farms with AMS. de Jong et al. (2003) found deviations in milk yield to be the most commonly used alert parameter (by 84% of farms). Milking interval was the second most used parameter (by 70% of farms), and electrical conductivity was used by 47% of farms to identify cows to place on attention lists. A survey of Canadian dairy

farms found 82% reporting health detection was easier with the AMS, while 19% reported health detection had become more difficult with the AMS (producers could respond health detection had become easier and harder) (Tse et al., 2017).

A challenge of these automatic herd monitoring systems is balancing the sensitivity and specificity of the alerts (Norberg et al., 2004). Standards for these systems require at least 70% sensitivity and 99% specificity, though most farms experience far fewer false positives per true case of mastitis than what the standards allow (Edmondson, 2012). However, different farmers have different tolerances for checking cows that have a false positive alert or cows with mastitis that get missed by the system (Mollenhorst et al., 2012; Claycomb et al., 2009). Farmers also rely heavily on their own intuition when deciding which cows to treat, whether the mastitis is detected manually by visual observation or via a sensing system, further complicating the automation of mastitis detection (Claycomb et al., 2009). de Jong et al. (2003) reported farmers reduced their dependence on electrical conductivity alerts for detecting mastitis over time. Therefore, it is suggested that farmers should be able to adjust alert settings to meet the needs of their management style (Mollenhorst et al., 2012). Additionally, while these automatic systems are useful for improved herd management and identifying cows needing attention, they are not a replacement for good management and handling of the cows to detect and prevent problems (de Jong et al., 2003).

Many dairies that have implemented AMS have also adopted activity and rumination sensors, as they are offered by AMS manufacturers (Jacobs and Siegford, 2012b).

Rumination sensors have been demonstrated to successfully aid in the detection of estrus (Reith and Hoy, 2012), health disorders (King, 2016), and cows that are close to calving (Schirrmann et al., 2013). Activity monitoring systems can also be an effective tool for the detection of estrus (Aungier et al., 2012; Holman et al., 2011).

SUMMARY

Investigation of Factors Associated with AMS Efficiency

The following chapters will describe how AMS are being implemented and evaluate what factors have influenced dairy farmers in the Midwest U.S. to adopt robotic milking. The US dairy industry is structured differently than in areas of more rapid AMS adoption and there is very limited research with AMS in the USA. There is a need to learn about factors at the farm and cow levels that are associated with increased efficiency of dairy production and the patterns of AMS use by individual cows.

Aspects of facility design are of interest, notably, the benefits of having a large open access area at the entrance to the AMS has been discussed by various authors in the literature (Jacobs and Siegford, 2012). However, the size of this area has not been assessed in relation to cow performance and social interaction in the commercial setting.

Scoring systems are commonly used to assess the wellbeing of dairy cattle on commercial dairy farms of all types and sizes. There is a need to describe the prevalence of lameness, severe hock lesions, and dirty cows in AMS, and investigate whether the prevalence of these measures of wellbeing are associated with productivity and efficiency of AMS use. This information will be useful for guiding the development of recommendations for better designing AMS facilities.

More research is needed to better understand how cows interact with the AMS on commercial dairy farms in the Midwest U.S. Evaluation of how daily milking frequency, failed visits, and refused visits to the AMS milking station change over the span of a lactation and differ between lactation groups (primiparous vs. multiparous) should provide for some understanding of cows' interaction with AMS.

Chapter 2

Farm characteristics and factors associated with lameness, severe hock lesion and hygiene of lactating dairy cattle on Upper Midwest US dairy farms using automatic milking systems**SUMMARY**

The objective of this cross-sectional study was to describe facility design, management practices, and farmer's perceptions on farms using automatic milking systems (AMS) in the Upper Midwest U.S. Another objective was to evaluate the association of various housing and management factors with 3 measures of animal health and welfare. Fifty-four farms were visited once to collect facility measurements and observations, interview the dairy producer, and score cows for locomotion, severe hock lesions, and hygiene. Median number of AMS units/farm was 2 (IQR 1; range 1 to 8). Factors concerning labor were the most commonly cited reason by dairy producers for making the transition to the AMS. Additional commonly cited factors were an improvement in lifestyle and human health. Number of cows fetched per AMS, or manually brought to the AMS if not milked voluntarily, was 4.7 ± 2.3 cows/AMS per d for free traffic flow farms and 3.3 ± 1.8 cows/AMS per d for guided traffic flow farms. Cow resting surface was associated with prevalence of lameness and severe lameness. Farms with sand-bedded freestalls (17.2%) and bedded packs (17.4%) had lower lameness prevalence than farms with

mattress freestalls (30.5%), waterbeds (25.0%), and mattresses with access to pasture (22.6%). Farms with mattresses and access to pasture had similar lameness prevalence to farms with waterbeds, but were lower than farms with mattresses only. A somewhat similar result was found for severe lameness prevalence; farms with sand bedded freestalls (2.8%), bedded packs (0.0%), and mattress freestalls with access to pasture (1.5%) had lower prevalence than farms with mattresses (7.1%) or waterbeds (10.8%). Severe hock lesion prevalence in herds with sand-bedded freestalls, waterbeds, and bedded packs were similar and lower than the prevalence in mattress-based freestalls. Cows housed in sand-bedded freestalls had lower prevalence of dirty cows than those housed on mattresses and waterbeds, and had lower prevalence of severely dirty cows than all other housing systems except waterbeds which was similar. Manure removal system was associated with prevalence of severely dirty cows; farms with manual scraping had lower prevalence of severely dirty cows than farms where alley scraping was practiced automatically or slatted floors were used. Dairy producers using AMS appeared to be successful with a variety of facility designs and management practices. Cow resting surface in AMS herds was associated with some animal health and welfare measurements.

INTRODUCTION

Many dairy farmers in North America have implemented AMS for a variety of reasons including improved quality of life, reducing issues associated with hired labor, and

improved quality of management of the dairy herd (de Jong et al., 2003). AMS have been paired with multiple different housing systems throughout the world, such as pasture-based (Lyons et al., 2013), freestall barns, and bedded pack barns (de Jong et al., 2003). Both free and guided flow cow traffic pattern have been successfully used in AMS, with findings from various studies identifying benefits and limitations to both traffic systems, including increased milk yield in free flow systems (Tremblay et al., 2016) but reduced need for fetching in guided flow systems (Ketelaar-de Lauwere et al., 1998).

Measures of animal welfare such as prevalence of lameness, severe hock lesions, and dirty cows have not been extensively investigated in AMS farms in North America. In addition, limited research has been conducted to evaluate the association of these measurements with various housing and farm management factors. Borderas et al. (2008) found lameness prevalence to be associated with lower milking frequency in AMS. Lameness is also a very costly disease, ranging in cost from about 120 to over 200 US dollars per case, depending on the type of lesion (Cha et al., 2010). A recent study in Canada (King et al., 2016) assessed lameness in AMS herds. They reported lameness and severe lameness prevalences were 26% and 2.2%, respectively.

The objective of this cross-sectional study was to describe facility design, management practices, and farmer's perceptions on farms using AMS in 2 states in the Upper Midwest U.S. In addition, the study investigated associations between some housing and

management characteristics and measures of health and welfare, including lameness, severe hock lesion, and dirty cow prevalence, which had not been previously studied in this region of the U.S.

MATERIALS AND METHODS

Farms

Fifty-four dairy farms in the Midwest U.S. (Minnesota and Wisconsin) using AMS were visited between June and September 2012 to collect on farm data for this observational study. At the time of enrollment, it was estimated (based on AMS dealer information) that these farms represented the majority (>85%) of the farms using AMS in these two states). Lely Astronaut (Lely Industries N.V., Maassluis, The Netherlands) and DeLaval VMS (Delaval International AB., Tumba, Sweden) AMS were used on the farms included in the current study. During farm visits, data were collected on barn design including number of AMS units per farm and per pen, whether the barns were built new or retrofitted, number of freestalls per pen (when applicable), type of manure removal system, cow resting surface, free or guided flow cow traffic, ventilation system, length of the exit lane from the AMS and open area in front of the AMS entrance, barn lighting, and the location and use of a footbath.

Farm owners were interviewed during the farm visit using a standardized questionnaire to collect data on their prior milking system, motivation for implementing automatic

milking, labor use, adaptation of the cows to the AMS, fetching routine and number of cows fetched per day, aspects of feeding management and nutrition, perceptions of the AMS, and experience with equipment failures and repairs.

Lameness Assessment

A minimum of 30% of cows in all pens as a representative sample of the herd (Endres, 2014) were scored for locomotion by a single trained observer using a 5-point scoring method (Flower and Weary, 2006), where 1 = normal, 2 = imperfect locomotion, 3 = lame, and scores of 4 and 5 = severely lame. Cow IDs were recorded by the observer to avoid scoring the same cow more than once; cows had to be scored by the observer as they walked in the freestall alleys. Cows were randomly selected throughout the pen and had to leave the stall upon request by the observer if they were in the stall so that every 2nd or 3rd cow was scored. Locomotion score data were used to calculate a prevalence of lameness (percent of cows scoring ≥ 3) and severe lameness (percent of cows scoring ≥ 4) in each pen.

Severe Hock Lesion Assessment

A minimum of 30% of cows in all pens as a representative sample of the herd (Endres, 2014) were similarly scored by a single trained observer for the presence of a severe hock lesion which was characterized by an open wound or swollen hock. Presence of a severe lesion on 1 of the hocks was sufficient to classify a cow as having a lesion. Prevalence of

hock lesion was calculated as the percent of cows scored with a severe lesion within each pen.

Hygiene Assessment

A minimum of 30% of cows in all pens as a representative sample of the herd (Endres, 2014) were similarly scored for hygiene by a single trained observer on a 5-point scale ranging from 1=clean to 5=extremely dirty (using 0.5-point increments). Hygiene of the lower hind legs and udder were assessed, as these areas of the cow have been found to be highly associated with somatic cell scores (Reneau et al., 2005). Scores of the udder and the 2 hind legs were averaged to obtain a single score for each cow. These scores were then used to calculate a prevalence of dirty and severely dirty cows for each pen. Cows with scores of 3 or 3.5 were categorized as dirty and cows scoring ≥ 4 were categorized as severely dirty.

Statistical Analysis

Descriptive statistics of the general farm parameters including number of AMS units per farm and per pen, number of cows in the herd before and after AMS installation, number of freestalls per pen, open area in front of the AMS entrance, length of the exit lane from the AMS, number of cows per full time equivalent (**FTE**) worker, number of cows needing fetching by traffic flow system/d, the minimum and maximum concentrate allowances in the AMS milking station and percent of forage in the partial mixed ration

(**PMR**), number of dealer calls/month, and alley scraping protocols by type of manure removal system, were evaluated using the MEANS procedure (SAS 9.4; SAS Institute Inc., Cary, NC). When data were normally distributed mean \pm SD are reported; when data were non-normally distributed, median, interquartile range (**IQR**), and range are reported.

The FREQ procedure (SAS 9.4) was used to describe the frequency of AMS by manufacturer, type of housing prior to AMS installation, motivation for adoption of AMS, new or retrofitted facility for the AMS, manure removal system, cow resting surface type, type of cow traffic flow, ventilation system, presence of cow grooming brushes, lighting and footbath protocols, cows' adaptation to the AMS, type of concentrate fed in the AMS, feed bunk management, and perceived factors for success with AMS.

The MIXED procedure (SAS 9.4) with the LSMEANS and PDIF options was used to evaluate the associations between lameness, severe hock lesion and dirty cow prevalence with cow resting surface, traffic flow system, manure removal system, whether the AMS was installed in a new or retrofitted barn, depth of the area in front of the AMS entrance area, length of the protected exit lane from the AMS, and use of a footbath. Farm was included as a random effect. A univariable analysis was first conducted with each variable and outcome of interest. Factors with a $P < 0.3$ were included in the initial multivariable model. Backwards elimination was used to remove non-significant factors until all remaining factors had a $P < 0.05$ in the final model.

RESULTS AND DISCUSSION

Farm Characteristics

Farms represented a variety of management styles and housing systems. Median number of AMS units/farm was 2 (IQR: 1; range: 1 to 8). Approximately 30% of the farms had DeLaval VMS and 70% had Lely Astronaut AMS. Farms had a median herd size of 100 milking cows (IQR: 80; range: 42 to 340) prior to the installation of an AMS. After the AMS installation, median herd size was 120 milking cows (IQR: 60; range: 60 to 480 cows). This is slightly larger than the herds surveyed by de Jong et al. (2003), where farms averaged 110 milking cows and 1.9 AMS/farm. This increase in herd size may be reflective of recent dairy industry trends for larger average herd sizes across the U.S. Recent economic models (Salfer et al., 2017) showed that AMS economic feasibility has improved over older models (Rotz et al., 2003), probably because of increased AMS performance and higher milking labor costs. Other non-economic factors such as the availability of labor or the desire for an improvement in lifestyle may be increasingly pertinent in making the decision between AMS and conventional milking systems.

Factors Influencing Decision to Transition to AMS

During the survey, farmers were asked about the primary motivations for transitioning to the AMS. The top 3 categories of reasons for transitioning to milking with an AMS were the ability to milk more cows with less labor, improved lifestyle, and human health (less risk of repetitive motion injury from the milking process). Labor was the most prevalent

factor, with 60% of the farms listing it as 1 of their top 3 reasons, and 43% as their number 1 reason for making the transition. Improvement in lifestyle and free time was the second most prevalent reason, with 55% of the farms reporting it as 1 of their top 3 reasons, followed by an improvement in human health with 28% of the farms reporting that as a factor. We also found that 23% of the farms needed to invest in new facilities and concluded that AMS was the newest technology available and likely the future of the milking process. In addition, 18% of the farms stated they desired to have access to more information and technology in managing their cows. Additional commonly reported factors in making the decision to transition to AMS included (in percent of farms reporting as one of their top factors) improvement in cow health (15%), expected increase in milk yield and/or milk quality (15%), consistency for the cows (13%), and individual quarter milking (10%). This feedback is comparable to the findings of Hogeveen et al. (2004), where they found reduced heavy labor (56%), and increased flexibility (35%), and less labor available (30%) as frequently reported reasons leading to farmers' decision in transitioning to AMS. Other reasons for choosing to implement an AMS that were commonly reported in both the current study and the study conducted by Hogeveen et al. (2004) include health of the cow, the need for investment in a milking system and the potential for increased milk yield. Interestingly, whereas 30% of the farmers reported being able to milk more than twice per day as a reason in the survey conducted by Hogeveen et al. (2004), only 5% of the farmers in the current study listed this reason as 1 of their top 3 motivations for installing the AMS.

Housing Prior to AMS Installation

Prior to installing AMS, 57% of the farms housed their cows in a tiestall or stanchion barn, 37% housed them in a freestall barn, and 6% did not report or used another type of housing system. Additionally, 43% of the farms were milking in a parlor before installation of the AMS, with the remainder milking in a tiestall or stanchion barn.

Housing After AMS Installation

In transitioning to using AMS, 56% of the farms in the current study built new facilities and 37% retrofitted existing facilities to install the AMS; 7% did a combination of retrofitting and building a new facility. Farms had a median of 1 AMS unit/pen (IQR 1; range 1 to 3). Farms had a median of 60 freestalls/pen (IQR 49.8; range 42 to 165). Manure removal was conducted using automatic alley scrapers in 46% of the herds, manual scraping in 26%, automatic scraping and slats in different pens in 4%, slatted floors without robotic scrapers in 11%, slatted floors with robotic scrapers in 7%, and bedded packs in 6%. Of the 49 herds housed with freestall beds, 55% had mattresses, 31% used sand bedding, and 14% had waterbeds. Seventy-four percent of the farms used free flow cow traffic, 24% guided flow cow traffic, and 2% both free flow and guided flow cow traffic in different barns. Guided flow was used in 4 different traffic patterns: freestalls to AMS to feed bunk (54% of the farms), freestalls to AMS to grain feeder to feed bunk (15%), feed bunk to AMS to feed bunk (15%), and feed bunk to AMS to freestalls (15%).

Barns on 65% of the farms were naturally ventilated, 22% of the farms used tunnel ventilation, and 13% were cross-ventilated. Rotating cow grooming brushes were used on 83% of the farms. Median open area in front of the AMS was 36.2 m² (IQR: 40; range: 11.1 to 187.3) and the median depth of this area extending out from the AMS was 6.1 m (IQR: 2.74; range: 2.1 to 12.2). The length of the exit lane from the AMS varied considerably from farm to farm. Median exit length was 2.4 m (IQR: 3.2; range: 0.3 to 8.53 m). Exit length is of interest as it may have an impact on how rapidly cows exit the AMS following milking, with longer exit lanes suggested to reduce the risk of a cow's exit from the AMS being blocked by another cow standing idle at the exit of the AMS (Rodenburg, 2004; Jacobs et al., 2012).

Lighting

Facility lighting practices varied considerably from farm to farm. Nineteen percent of the farms left the lights on in the barn and AMS area 24 h/d. Eighty-three percent provided light (either natural or artificial) around the AMS area 24 h/d whereas the remaining 17% of the farms had no lighting around the AMS for at least part of the night. Forty percent of the farms had scheduled long-day lighting in the pen (described as between 16 and 18 h of light/d). Thirty-two percent of the farms provided more than 18 h of light/d, whereas the remaining 28% of the farms provided less than 16 h of light/d. In conventional systems, long-day lighting has been shown to have a positive association with milk yield (Dahl et al., 1997).

Footbath Use and Location

A footbath was used on 70% of the farms. Nineteen percent of the farms that did not use footbaths used a spray-on hoof health product in the AMS. Of the farms using footbaths, 38% used them once/wk or less, 35% of the farms used them 2 to 3 times/wk and 27% used them > 3 times/wk. Twenty-four farms provided the location of the footbath; 71% placed the footbath at the exit of the AMS, 4% placed it at the end of the barn, and 25% placed the footbath somewhere else in the pen. Some farms did not want to install the footbath near the AMS unit because of the concern that it may affect visits to the AMS milking station. There is a need for more research on what is the best location within the barn for installing footbaths in AMS farms.

Labor on AMS farms

Fifty-one farms provided information on labor efficiency, a major factor for farms choosing to adopt robotic milking. These farms managed their herd with a median of 96 (IQR: 69; range: 28 to 180) cows/FTE. Five farms managed with over 150 cows per FTE. In comparison, Caraviello et al. (2006) reported that conventional dairy farms (average herd size of 613 cows) had 84 cows/FTE. Bewley et al. (2001) reported that smaller Wisconsin herds (up to about 300 cows/herd) using parallel or herringbone parlors had 40 to 45 cows per FTE. It appears that AMS farms compare favorably with larger farms from a labor standpoint.

Adaptation of Cows to the AMS

Adaptation of the cows to be milked voluntarily by the AMS is a concern for people considering the installation of AMS. From the responses of 37 of the farms in the study, 38% reported having $\leq 1\%$ of cows failing to adapt to the system, 49% had $> 1\%$ but $\leq 5\%$ adapt, 3% had between 5% and 10% fail to adapt, and 11% had $\geq 10\%$ fail to adapt. An additional 4 farms continued to milk cows that did not adapt to the AMS in a conventional milking parlor. Rodenburg (2002) reported Ontario farms experienced 0 to 3 additional involuntary culls annually (mean herd size of 94 cows) due to udder conformation issues, particularly with rear teats placed too close together or too far back on the udder.

Fetching Cows to Be Milked

Although most cows visit the AMS voluntarily, farm workers need to routinely bring cows to the AMS that failed to visit the AMS milking station on time as defined by the permission settings for milking interval on each farm. These cows are flagged by the AMS software in a daily attention list. Data on fetching was available for 41 of the farms, of which 66% had free flow systems and 39% had guided flow systems (2 farms utilized both free and guided flow designs). Seventy-eight percent of these farms fetched cows to the AMS < 2 times/d, 17% fetched cows 2 to 3 times/d, and 5% fetched cows > 3 times/d. Free flow farms reported fetching 4.7 ± 2.3 cows/AMS per d (mean \pm SD). Farms using guided flow traffic pattern reported fetching 3.3 ± 1.8 cows/AMS per d.

Rodenburg (2007) reported that farms fetch 16.2% of the herd in free traffic systems and 8.5% in guided traffic flow systems; which, assuming 60 cows/AMS station, would be 10 and 5 cows per AMS per day for free and guided flow systems, respectively.

Feeding Management and Nutrition

Forty-one of the farms we visited provided information on the AMS feeding practices they used. Of these farms, 95% fed pellets in the AMS milking station, 2.5% fed both a meal and pellets, and 2.5% (which was a certified organic farm) fed soybeans and oats. Five percent of the farms that fed pellets supplemented fresh cows with pellets and meal. Other farms had previously fed a meal in the AMS but had since transitioned to a pellet. Access to palatable feed in the AMS milking station is critical for AMS farms' success as the opportunity to receive concentrate feed is a greater motivation for cows to visit the AMS milking station than the opportunity to be milked (Prescott et al., 1998).

Rodenburg et al. (2004) reported that feeding harder pellets less prone to crumbling was associated with more frequent cow visits to the AMS and reduced need for fetching compared to feeding softer pellets. Pelleted feeds have also been shown to be preferred over meals (Spörndly and Åsberg, 2006).

Thirty-nine farms provided information about the amount of feed offered through the AMS milking station. The mean amount allowed per cow per day in the AMS was 1.9 ± 1.1 kg for guided flow and 6.6 ± 2.5 kg for free flow traffic farms. The concentrate

feeding amounts observed in the current study in the free flow traffic farms, were greater than those suggested by Bach and Cabrera (2017), where limiting concentrate allowance to less than 3 to 4 kg/d with no more than 1.5 kg fed per milking was recommended.

The partial mixed ration (PMR) delivered in the feed bunk in AMS is expected to have higher forage content than total mixed rations in a conventional milking system because some or all concentrate is offered in the AMS milking station. Percent forage in the PMR (DM basis) was $75 \pm 17\%$ (range: 46 to 100%) in 25 farms reporting this information in the current study. Twelve percent of the farms fed 100% forage in the PMR; 67% of these herds were certified organic. Twenty-five percent of the farms used pasture as the primary summer forage; 80% of these farms were certified organic.

Feed push-up protocols varied considerably among farms. Of 43 farms for which data were available, 35% had an automatic feed pusher, 21% utilized a feed bunk system where feed push-ups were not necessary (either “J” bunks or “H” bunks where cows had access to both sides of the bunk), and 44% pushed up feed manually. For those farms manually pushing up feed, 47% of them pushed up feed 1 to 3 times/d and 53% pushed up feed 4 to 12 times/d. Most of the automatic systems pushed up feed every hour or every other hour, resulting in 12 to 24 feed push-ups/d on those farms. King et al. (2016) found a positive association between lying time and the number of feed push-ups per day in AMS herds in Canada. However, DeVries et al. (2003) and Bach et al. (2008) found no

association between feed push-up frequency and measures of milk production efficiency in AMS herds.

Perceived Factors for Success

We asked 41 of the farms what they believed to be some of the most important factors for success when managing cows in an AMS. Responses varied considerably, but feeding and nutrition, computer use, and cow management were reported by 51%, 41% and 37% of the farms, respectively. Other commonly reported factors included spending time watching cows, keeping on top of AMS maintenance, barn layout and design, as well as patience and the ability to be adaptable. These responses were similar to those reported by de Koning and van der Vorst (2002) as keys to successfully implementing and managing an AMS dairy farm.

Calls from AMS

The AMS are designed to contact a predetermined person's cell phone when issues arise with the system. Thirty-two farms provided estimates of the frequency of calls from the AMS, of which the farm with the most calls received 43 calls/AMS per mo, whereas the farm with the least number of calls received 0.5 calls/AMS per mo. Seventy percent of the farms received ≤ 5 calls/AMS per mo, 20% received 6 to 15 calls/mo and 10% received ≥ 16 calls/mo. The most common reason for calls from the AMS were hose-related issues (74%), followed by rope-related issues (18%), laser or sensor issues (13%)

and washing system (13%). Other less commonly reported reasons included problems with the air compressor, electrical issues, and power related issues (such as power outages). The farmers were asked about the frequency of having to call the AMS dealer to assist with repairs, which they reported calling a median of 1 (IQR: 1.5; range: 0 to 4) time/mo. Some farmers reported they never called the dealer for assistance and had a trained person on the farm that was able to troubleshoot and fix problems. Most AMS farmers did not find the calls to be a major concern. AMS users are allowed to select the sensitivity and type of alarms that are sent to their cell phones. It is possible that farms receiving more calls had the more sensitive alarm settings. Other reasons may be the lack of routine machine maintenance, cow behavior, or a higher percent of cows that are not fully adjusted to the robot.

Limited data were provided in terms of repair costs, as some farmers were unsure of their annual repair expenses and others had only been using the AMS for a relatively short amount of time and had not experienced major repairs or all repairs that had occurred had been covered by the manufacturer's warranty. Perceptions of repair costs varied considerably, as some farms reported repair expenses to be "minimal" and others experiencing "higher than expected" repair costs.

Lameness Prevalence

Data from 52 farms (93 pens; 3,273 cows) were included in the analysis of lameness prevalence. Resting surface type, manure removal system, whether the farm built a new barn or retrofitted an existing facility and depth of the area at the AMS entrance were included in the initial multivariable model for their association with lameness prevalence. After backwards elimination, only resting surface was retained in the final model. Lameness prevalence was $17.2 \pm 2.6\%$ (Least Squares Mean \pm SE) for sand-bedded farms, $22.6 \pm 4.3\%$ for farms with mattresses and pasture access, $17.4 \pm 5.6\%$ for bedded pack systems, $25.0 \pm 3.7\%$ for farms with waterbeds and $30.5 \pm 1.9\%$ for farms with mattresses. Lameness prevalence was greater for herds with mattresses than herds with bedded packs ($P = 0.033$), sand-bedded stalls ($P < 0.001$), and tended to be greater than mattresses with pasture access ($P = 0.091$). Herds with waterbeds tended to have greater lameness prevalence than sand-bedded systems ($P = 0.092$), and were similar to mattress with pasture access systems ($P = 0.677$).

For severe lameness prevalence, resting surface type, manure removal system, cow traffic flow, whether a footbath was used, depth of the area in front of the AMS entrance, and length of the exit lane from the AMS were included in the initial multivariable model. After backwards elimination, only resting surface and length of the exit lane remained in the final model ($P < 0.05$). Similar associations were found for severe lameness prevalence, where herds with sand, bedded packs, and mattresses with pasture access had

a prevalence of $2.8 \pm 1.3\%$, $0.0 \pm 0.3\%$, and $1.5 \pm 0.5\%$, respectively, which was lower than mattresses and waterbeds with $7.1 \pm 1.0\%$ and $10.8 \pm 1.8\%$, respectively ($P < 0.05$). Farms with waterbeds tended to have greater severe lameness prevalence than those with mattresses ($P = 0.085$). Length of the exit lane from the AMS was negatively associated with severe lameness prevalence ($P = 0.031$).

These differences in lameness and severe lameness prevalence between systems are of interest because, as reported previously by Borderas et al. (2008), a greater proportion of cows having a low number of daily visits to the AMS were lame compared to the cows with the greatest number of daily visits. King et al. (2016) found severe lameness prevalence was associated with reduced milking frequency and milk yield per AMS. Bach et al. (2007) also reported reduced number of visits to the AMS with increased locomotion score, as well as reduced DMI, reluctance to travel farther from the AMS to obtain feed, and reduced milk yield. Reduction in milking frequency among lame cows was also found by Klaas et al. (2003). Overall, the prevalence of lameness and severe lameness was higher relative to that found by Westin et al. (2016) in Canadian dairy farms, where mean lameness and severe lameness prevalence was 15% and 4%, respectively. However, depending on resting surface type, result of the current study were more similar to those of King et al. (2016) assessing the association of housing and management factors with lameness and productivity in Canadian AMS herds, where lameness and severe lameness prevalence were 26% and 2.2%, respectively.

Hock Lesion Prevalence

Data from 52 farms (93 pens; 3,249 cows) were included in the analysis of severe hock lesions. Resting surface type, manure removal system, cow traffic flow, and length of the exit lane from the AMS met the criteria for inclusion in the initial multivariable model. After backward elimination, resting surface type was retained as significant. Farms with sand, waterbeds, and bedded packs had severe hock lesion prevalence of $3.3 \pm 2.2\%$, $8.0 \pm 3.3\%$ and $1.9 \pm 4.9\%$, respectively. These were lower ($P < 0.05$) than the severe hock lesion prevalence in herds with mattresses ($16.2 \pm 1.7\%$). The combined mattress and pasture system had a severe hock lesion prevalence of $13.8 \pm 3.9\%$ which was greater ($P = 0.025$) than the sand-bedded freestalls, tended to be greater ($P = 0.067$) than bedded pack systems, but similar to the waterbed ($P = 0.261$). These results are similar to the findings of Fulwider et al. (2007), where conventional farms with rubber filled mattresses had greater lesion prevalence than farms with sand bedding or waterbeds.

Hygiene

Resting surface type, manure removal system and traffic flow type were included in the initial multivariable models for assessing the association of housing factors with prevalence of dirty and severely dirty cows. Backwards elimination removed traffic flow from both models and manure removal system from the dirty cow prevalence model. Resting surface type was retained in both models and manure removal system was also found to be associated with prevalence of severely dirty cows. Prevalence of dirty cows

was similar for farms with mattresses, waterbeds, bedded packs, and mattresses with pasture access. Farms with sand-bedded freestalls tended to have ($P = 0.095$) a lower prevalence ($39.0 \pm 6.9\%$) of dirty cows than those with mattresses and pasture access ($59.4 \pm 9.9\%$), and had lower prevalence of dirty cows compared to farms with mattresses ($P = 0.001$) and waterbeds ($P = 0.002$). Sand and bedded packs ($64.6 \pm 14.4\%$) were not different ($P = 0.104$).

Similar findings were obtained for prevalence of severely dirty cows. Farms with mattresses, waterbeds, and mattresses with pasture access had similar severely dirty cow prevalences of $18.6 \pm 2.6\%$, $18.6 \pm 5.2\%$, and $25.0 \pm 5.9\%$, respectively. Farms with sand-bedded freestalls had a lower prevalence ($8.4 \pm 3.9\%$) than mattresses ($P = 0.034$), bedded pack ($P = 0.004$), and mattress with pasture access ($P = 0.024$), but were similar to waterbeds ($P = 0.126$). Bedded pack farms had a higher prevalence of severely dirty cows (36.4%) than mattress ($P = 0.048$) and sand ($P = 0.004$), tended to be higher than waterbeds ($P = 0.082$), and were similar to mattresses with pasture access ($P = 0.264$). Farms with waterbeds tended to have lower prevalence of severely dirty cows than bedded packs ($P = 0.082$). These findings contradict those of Fulwider et al. (2007) where cows housed on sand were dirtier than those on mattresses or waterbeds.

Prevalence of severely dirty cows in manually scraped systems ($12.6 \pm 3.4\%$) was lower than both automatically scraped ($22.4 \pm 3.2\%$; $P = 0.025$) and slatted floor pens ($29.1 \pm 4.3\%$; $P = 0.003$), which were similar to each other ($P = 0.155$). Farms with

automatically scraped pens had a median of 12 scrapings/d (IQR: 6.4; range: 1 to 24) compared to the manually scraped pens which had a median of 2 scrapings/d (IQR: 0; range: 1 to 3). The higher hygiene scores of farms with automatically scraped barns may be attributed to cows walking through the deeper slurry of manure being pushed by the alley scraper, causing them to be dirtier. DeVries et al. (2012) found increased frequency of alley scraping to be associated with improved hygiene scores. Due to a limited number of pens with slatted floors, slatted floor barns with and without an automatic alley scraping system were not separated in the analysis for the current study. Magnusson et al. (2008) found that slatted floor pens scraped with an automatic scraper compared to slatted floor with no scraping had a 27% and 37% lower prevalence of dirty udders and teats, respectively. Keeping cows clean is an important factor for success in AMS herds. Dohmen et al. (2010) showed that the annual average herd SCC in AMS herds was positively associated with the proportion of cows with dirty teats before milking and the proportion of cows with dirty legs. In addition, the annual average percentage of new cows with high SCC was positively associated with the proportion of cows with dirty teats before milking. At the cow level, hygiene scores of the udder, thighs, and legs were positively associated with SCC.

CONCLUSIONS

Farms were using AMS in a variety of facility designs in 2 states in the Upper Midwest U.S. Both free flow and guided flow systems appeared to have been implemented successfully and did not differ in terms of welfare measurements assessed in this study. Cow resting surface was associated with lameness prevalence, severe hock lesion prevalence, and prevalence of dirty and severely dirty cows. Manure removal system was associated with prevalence of dirty and severely dirty cows. It is suggested that factors of facility design and management practices that minimize prevalence of lameness, hock lesions, and dirty cows will help AMS be more successful, and should be taken into consideration when installing new AMS or improving the facilities and management of farms currently using AMS.

Chapter 3

Farm level factors associated with milk yield of dairy farms using automatic milking systems in the Upper Midwest U.S.**SUMMARY**

Multiple reasons have led to the increase in use of AMS in the Upper Midwest U.S. in recent years. The objective of this study was to identify housing and management factors associated with productivity in AMS farms measured as both milk yield per cow per day and milk yield per AMS unit per day. Data were collected from 33 AMS farms in the Midwest U.S. using free flow cow traffic. Farms with automatic feed push-up via a robot produced more milk than farms where feed was pushed up manually, whereas farms using contained bunk (“H” or “J” bunk) systems produced intermediate and similar amounts of milk to the other 2 systems. New versus retrofitted facility, stall surface type, manure handling system, and the number of AMS units per pen were not associated with milk yield. Cow comfort index (CCI) was positively associated with milk yield per cow/d. Prevalence of lameness and severe lameness, number of cows per full-time equivalent employee, depth of the area in front of the AMS milking station, and length of the exit lane from the AMS milking station were not associated with milk yield per AMS/d or per cow/d. A multivariable model with AMS software data from 32 farms collected daily over approximately an 18-mo period found farms with more mature herds,

greater milking frequency, longer milking time, more cows per AMS, and feeding greater amounts of concentrate per day to be positively associated with milk yield per AMS. Factors negatively associated with yield per AMS were greater numbers of failed and refused visits to the AMS, longer treatment time (the time spent prepping the udder prior to milking and applying a teat disinfectant after milking), and greater amounts of residual feed left unconsumed due to a lack of visits to the AMS. Similar results were also found for milk yield on a per cow/d basis; however, average DIM of the herd was also negatively associated with milk yield. These findings reinforce the necessity for excellent cow management and care, as well as the need for efficient use of the AMS's daily time budget to allow for the system's success.

INTRODUCTION

Since the first commercial automatic milking system (AMS) installation on a dairy farm in 1992 in The Netherlands, dairy farmers around the world have chosen to adopt this technology for various reasons. Barkema et al. (2015) reported AMS to be in use on over 25,000 farms worldwide. Due to different climates, cultures, and economic situations of individual farms and regions as a whole, AMS have been implemented and managed in a variety of methods throughout the world. However, within regions, management and facility design also varies considerably. Implementation of AMS on farms in the Midwest U.S. has increased and there is a need for information on factors associated with their productivity on farms in this region.

Many suggestions for facility design and management have been made but many have not been evaluated in a study. Having a large open area in front of the AMS entrance has been suggested to improve cow flow into and around the AMS (Rodenburg and House, 2007). Longer exit lane length was indicated by Jacobs et al. (2012) to potentially be associated with improved cow flow when exiting the AMS due to reduced blocking events by other cows in the pen. However, neither of these factors - which can have economic implications for farmers designing facilities with AMS - has been scientifically evaluated. Limited data exist concerning the practice and frequency of feed push-up. Studies conducted by DeVries et al. (2003) and Bach et al. (2008) evaluated pushing up feed up to 4 times/d which is considerably less frequent than what is conducted with automatic feed push-up systems, where feed is generally pushed up every hour or every other hour.

Limited research has been conducted to analyze daily data recorded by the AMS software from a representative number of farms in the same region over an extended period of time to evaluate factors associated with the efficiency of AMS use. Tremblay et al. (2016) evaluated weekly data from a large number of farms from across North America; however, regional differences in climate, management practices, and affordable feed resources may lead to differences in management recommendations for different areas. In addition, previous studies have not included factors such as AMS unit treatment time, average age of the herd, type of stall surface, or manure handling system.

Therefore, the objective of this study was to investigate the association between daily milk yield and facility design and management on dairy farms with AMS in 2 states of the Upper Midwest U.S. (Minnesota and Wisconsin). All farms in the current study used free flow cow traffic, meaning cows could freely move among the feeding, resting and AMS station without guidance by one-way gates to the AMS station or a sorting system that determines if the cow must first be milked before being released to the feeding or resting area.

MATERIALS AND METHODS

Thirty-three dairy farms in the Midwest U.S. (Minnesota and Wisconsin) utilizing AMS were visited once to collect data on management practices and facility designs. All farms used a free flow pen design, i.e. cows were allowed to move between the resting area, AMS unit and feeding area freely and had no pasture access. These farms were estimated (based on dealer information) to represent the majority (> 85%) of confinement farms with free flow AMS in these two states at the time of initiation of the current study. The free flow system was associated with greater milk yield in a study with a large number of North American herds (Tremblay et al., 2016). Observational data of facility design were collected from each pen where an AMS was used to milk the cows. Twenty-three percent of farms continued to milk fresh cows and special needs cows in a conventional milking system; however, those cows and their environment were not included in the current study.

Facility design measurements included depth of area in front of the AMS unit (m) and length of the protected lane at the exit of the AMS (m). Other observations included whether the dairy chose to build new facilities or retrofit existing facilities when installing the AMS, what type of stall surface was used, type of manure removal system, and how many AMS units were installed per pen. Stall surface was categorized as mattresses, deep sand, and waterbeds. Two farms using bedded pack systems were excluded from this analysis. Manure removal system was categorized as automatic scraping of alleys, manual alley scraping, and slatted alley floor with a manure containment pit below the barn. All lactating cows in the current study were housed in a barn and did not have access to pasture. Number of AMS units was categorized into either 1 AMS unit/pen or >1 AMS unit/pen.

Cow Comfort Index (CCI) was calculated by dividing the number of cows lying in a stall by the number of cows touching a stall (cows lying in the stall plus cows standing with 2 or 4 feet in the stall). CCI could not be calculated on 2 farms because they used a bedded pack housing system and 3 other farms for which this measurement could not be collected. Espejo and Endres (2007) found CCI to be negatively associated with lameness prevalence in a study with freestall farms in Minnesota.

A minimum of 30% of cows in all pens as a representative sample of the herd (Endres, 2014) were scored for locomotion by a single trained observer using a 5-point scoring

method (Flower and Weary, 2006), where 1 = normal, 2 = imperfect locomotion, 3 = lame, and scores of 4 and 5 = severely lame. Cow IDs were recorded by the observer to avoid scoring the same cow more than once; cows had to be scored by the observer as they walked in the freestall alleys. Cows were randomly selected throughout the pen and had to leave the stall upon request by the observer if they were in the stall so that every 2nd or 3rd cow was scored. Locomotion score data were used to calculate prevalence of lameness (percent of cows scoring ≥ 3) and severe lameness (percent of cows scoring ≥ 4) in each pen.

Data from 32 farms from the daily farm summaries recorded by the AMS software for a period of 18 mo were used to summarize information on AMS use and productivity of the herd. The variables used in this analysis included (all of which are an average on a per farm basis unless specified otherwise): daily milk yield (per cow and per AMS), days in milk (DIM), age of the herd, number of milking visits, number of refused milking visits, number of failed milking visits, amount of concentrate fed, amount of residual concentrate feed not dispensed from the AMS, cow milking speed, milking time per visit, treatment time (the time required to prepare the udder for milking and post dip) per visit, and number of cows per AMS milking unit. One farm was excluded from this analysis due to missing data.

Statistical Analysis

Descriptive Data.

The FREQ procedure in SAS 9.4 (SAS Institute Inc., Cary, NC) was used to calculate the frequency of new vs. retrofitted facilities where the AMS was installed, as well as type of freestall surface, manure handling system, number of AMS units/pen, and feed bunk management system.

Descriptive statistics were computed using the MEANS procedure (SAS 9.4). When the data were normally distributed, mean \pm SD are reported, and when data were non-normally distributed, median, interquartile range (**IQR**), and range were reported. CCI, prevalence of lameness, cows per full-time equivalent (**FTE**), age of cows within the herd, number of milking visits/d, amount of concentrate fed in the AMS unit (kg/cow per d), amount of residual feed left unconsumed at the AMS (kg/cow per d), milking time (sec/cow per d), treatment time (sec/cow per d), and cows per AMS unit were assumed to have normally distribution. Non-normally distributed factors included severe lameness, depth of the area extending out from the AMS entrance, length of the exit lane from the AMS, average DIM of the herd, number of refused visits to the AMS/d, number of failed milking visits to the AMS/d, and cow milking speed (L/min).

Cross Sectional Data

Data from categorical variables were used to evaluate their association with average milk yield per AMS/d and per cow/d using univariable analysis. PROC MIXED in SAS with the LSMEANS statement and PDIFF=ALL option was used to determine differences of least squares means. Farm was used as the experimental unit (n=32). Categorical variables included were whether the AMS was installed in a new barn or retrofitted into an existing facility, manure removal system, free stall surface type, AMS units per pen, and feed push-up method.

Continuous variables of facility design and management were analyzed using linear regression. The model was fit using Proc MIXED (SAS 9.4) for their association with average milk yield/AMS per day and per cow per day using univariable analysis. Farm was used as the experimental unit (n=33). Independent variables included were cow comfort index (**CCI**), lameness prevalence, severe lameness prevalence, cows per full time equivalent (**FTE**), depth of the open area extending out from the AMS preceding the entrance to the AMS, and length of the exit lane from the AMS

Longitudinal Data

Longitudinal data collected daily from the AMS software were used to evaluate the association of those factors with milk yield per cow/d and per AMS/d. Factors evaluated include average DIM of the herd and age of the herd; average milking, failed, and refused

visits to the AMS/cow per day; concentrate feed consumed and amount left undispensed or unconsumed (Kg/cow per d); milking speed (L/min), milking time and treatment time (time spent prepping the udder and applying teat dip after milking), and the number of cows per AMS. A univariable analysis was first conducted with each variable and the 2 outcomes of interest (milk yield/cow per d and milk yield/AMS per d). Factors with a $P < 0.3$ were included in the initial multivariable model (Proc MIXED, SAS 9.4). Backwards elimination was used to remove non-significant factors until all remaining factors had a $P < 0.05$ in the final model.

RESULTS AND DISCUSSION

Descriptive Statistics

Cross sectional Data

Fifty-five percent of the farms built new facilities when installing the AMS and 45% retrofitted existing facilities to accommodate the new milking system. For freestall surface, 48% of the farms had mattresses, 39% used sand bedding, and 12% had waterbeds. To remove manure in the alleyways of the pens, 52% of the farms had automatic scrapers, 33% scraped the pens manually, and 15% had slatted floors. Pens were designed with 1 AMS/pen on 58% of the farms and with 2 or more AMS/pen in at least 1 of the pens on 42% of the farms. Nine percent of farms had a mix of pens with single milking units or multiple milking units, while 33% had multiple units in each pen.

A robotic feed pusher was used on 31% of the farms, manual pushing up of the feed on 50% of the farms, and a fixed bunk to contain the feed (“H” or J” type of bunk) on 19% of the farms. CCI was $75.8 \pm 11.7\%$ (mean \pm SD). Lameness prevalence was $25.6 \pm 10.8\%$ and median severe lameness prevalence was 4.4% (IQR 5.6; range 0 to 16.1). Number of cows/FTE was 89.7 ± 34.0 . Median depth of the area at the entrance to the AMS was 6.1 m (IQR 1.63; range 3.1 to 11.5). Median length of the exit lane from the AMS was 2.6 m (IQR 2.7; range 0.3 to 8.5). Average milk yield, measured on a per cow per day basis varied considerably between farms (Figure 1), ranging from about 20.9 Kg/cow per day to almost 40 Kg/cow per day.

Longitudinal Data

Median DIM was 173 (IQR 14.6; range 142.8 to 241.6). Age of cows within the herd was 48.9 ± 4.8 mo. Milk yield was 33.2 ± 5.3 kg per cow/d and 1861.1 kg per AMS/d. Cows averaged 2.8 milking visits to the AMS/d, had a median of 0.8 refused visits to the AMS/d (IQR 0.5; range 0.4 to 3.5), and a median of 0.076 failed milking visits at the AMS/d (IQR 0.033; range 0.26 to 0.36). Amount of concentrate fed in the AMS averaged 5.0 ± 0.8 kg/cow, and residual concentrate feed left/cow due to a lack of milking visits averaged 0.27 ± 0.12 kg/cow. Median cow milking speed was 2.7 L/min (IQR 0.3; range 2.3 to 5.0). Milking time averaged 332 ± 33 sec and treatment time (time spent in the AMS not being milked) averaged 122 ± 22 seconds. Median herd size was 115 cows (IQR 94; range 56 to 472) with 55.8 ± 6.1 cows/AMS unit.

Cross Sectional Factors

Whether to build new or retrofit existing facilities when transitioning to an AMS has been a topic of discussion in the industry and is part of the decision making process for farmers prior to making the transition (Rodenburg, 2010). We did not find a difference in productivity between new and retrofitted facilities (Table 1). This could be because farms that chose to retrofit had better existing facilities than farms choosing to build new, resulting in milk yield not being restricted by the quality of those existing facilities in comparison to the farms that chose to build new. Tremblay et al. (2016) also reported building a new facility or retrofitting existing facilities not to be associated with milk yield/AMS. The decision to build new or retrofit existing facilities will likely be influenced by other factors on the farm, such as usability of facilities, differences in labor efficiency, and cost of building new versus retrofitting. Rodenburg (2010) recommended that farms weigh the total costs and benefits of retrofitting compared to building new before making a final decision.

Manure removal system and stall surface type were not associated with milk yield per AMS or per cow. Eighty percent of the farms with slatted floor barns used an automatic scraping robot (Lely Discovery, Lely Industries N. V., Maassluis, The Netherlands) to push manure through the slats. Although no association was found between alley scraping system and milk yield, Rodenburg (2004) suggested that use of automatic

scrapers or slats could be advantageous because entry of machinery into the pen can be disruptive to the cows.

The optimal number of AMS units per pen has been of discussion in the industry as farms are deciding how to design their barns (Rodenburg, 2010). Many factors play into this decision including herd size, grouping strategies, and ease of fetching cows that do not voluntarily visit the AMS (Rodenburg, 2010). We did not find a difference in milk yield between farms with 1 AMS/pen and those with >1 AMS/pen. This contradicts the findings of the study conducted by Tremblay et al. (2016) of a larger number of herds, where a significant association was found between AMS/pen and milk yield/AMS with 2 AMS/pen associated with higher milk yield than 1 AMS/pen. Some producers have reported that when an AMS unit is out of use for an extended period of time due to repairs being performed (more than a couple hours), they have experienced less dramatic production losses when there is another AMS unit in the pen that can continue to be accessed for milking (Rodenburg and House, 2007).

Feed push-up method was associated with milk yield per AMS and per cow per day. Farms with automatic feed push-up (feed push-up robot) produced 352 kg more milk/AMS and 4.9 kg more milk/cow per day than farms that manually pushed up feed (Table 1) which would be equivalent to approximately \$45,000 more/AMS per yr for farms using automatic feed push-up (assuming a milk price of \$0.35USD/Kg; excluding

costs of operating, maintenance, etc.). Milk yield for farms with a bunk where feed push-up was not necessary (fixed bunk that retained feed near the feed barrier; e.g., “J” or “H” bunk) was intermediate and not different from the farms where feed was automatically or manually pushed up. Automatic feed push-up allows for the task to be performed on a consistent schedule and up to 24 times/d on many farms. Increased feed push-up allows for potentially more consistent access to feed throughout the day and more efficient feed consumption when cows are at the feed bunk. Previous research with conventional systems has not found an association between feed push-up frequency and milk yield (DeVries et al., 2003, Bach et al., 2008); however, these studies only pushed up feed up to 4 times/d, which is similar to the feed push-up schedule performed on many of the farms in the current study that manually pushed up feed. Additionally, with the implementation of AMS milking, farmers may not be in the barn as frequently or consistently to push up feed as when milking with a conventional system. This may result in some days where feed push-ups are performed less frequently than what the producer reported, having a negative effect on milk yield. The differences between feed bunk management systems are not expected to be the result of the actual activity of pushing up feed, as DeVries et al. (2003) found pushing up feed to have very limited impact on stimulating cows’ visits to the feed bunk, especially in comparison to feeding and milking activities. Generally, both the automatic push-up and fixed bunk system provide for feed being accessible on a continuous basis. Management factors, such as targeted refusal rates, which were not measured in this study, could help explain why

farms using a contained bunk did not produce more than farms using manual feed push-up.

CCI, a measure of free stall usability and comfort was positively associated with milk yield/cow ($P=0.035$), indicating this may be a simple, useful tool to be used on farms when evaluating cow comfort. Espejo and Endres (2007) found CCI (referred to in that study as cow comfort quotient) as having a negative association with lameness prevalence. Although CCI was associated with milk yield in the current study, both lameness and severe lameness prevalence were not found to be associated with milk yield/AMS or per cow. This contradicts the findings of Bach et al. (2007) where increased lameness prevalence was associated with decreased milking frequency and milk yield. Factors such as potentially increased fetching of lame cows or changes in lameness prevalence over the period of time when milk production data were collected (as lameness was only assessed at one visit), may have impacted the association lameness had with milk yield in the current study.

Depth of the area in front of the AMS was not associated with milk yield per cow or per AMS. This variable was included in the analysis, as some discussions of our team with various consultants suggested that having less open space would increase the likelihood of cows blocking the entrance, therefore causing cows to remain standing idle for longer periods of time waiting to enter the AMS. This could cause a reduction in AMS milking

visits, leading to reduced milk yield. Based on field experience, Rodenburg and House (2007) stated that having a larger open area in front of the AMS improved cow flow. It may be that the area in front of the AMS was generally adequate on the farms in the current study and not limiting cow flow.

No association was found between length of the exit lane from the AMS with milk yield per AMS or per cow. It has been suggested that longer exit lanes from the AMS help facilitate improved cow flow through the AMS unit, and help prevent blocking events where the AMS unit is unavailable for subsequent milkings due to a cow being unable to exit the AMS unit (Jacobs et al., 2012).

Longitudinal Factors

All factors from the univariable analyses met the criteria for inclusion in the multivariable regression models (P -values < 0.16). In the milk yield/cow per d multivariable model no variables were removed with backwards elimination (Table 2), as all had an association ($P < 0.05$) with the outcome variable. Average DIM for the herd was removed from the milk yield/AMS per d (Table 3) multivariable model ($P = 0.072$).

Factors associated with milk yield per cow per day are shown in Table 2 and those associated with milk yield per AMS per day in Table 3. Average milkings per day was

positively associated with productivity, both per cow and per AMS. This supports the findings of Løvendahl and Chagunda (2011) in an analysis of individual cow data where they also found a positive effect on milk yield from increased milkings per day in AMS farms. Wagner-Storch and Palmer (2003) also found increased milk yield in an AMS compared to a conventional milking system and found the greatest contributor to the increased milk yield was an increase in milking frequency. Cows milked more frequently during early lactation (3 times/d vs. 6 times/d) in conventional milking systems had reduced somatic cell scores and higher milk yield (Dahl et al., 2004).

Average refused and failed visits had a negative association with both daily milk yield per cow and per AMS. Refused visits are a result of cows visiting the AMS prior to the minimum time interval in between milkings from permission settings. Failed visits (milking units do not attach to the teats and cow does not get milked when she should be based on permission settings) can result from multiple factors caused by either the cow or equipment malfunctions. Tremblay et al. (2016) also found a negative association of refused and failed visits to the AMS with milk yield. Bach and Busto (2005) found quarters that experienced milking failure produced a similar amount of milk at the subsequent milking event but had lower milk yield when measured on a per hour basis due to the increased milking interval.

Average concentrate fed/cow per day was positively associated with daily milk yield, both per cow and per AMS; with farms feeding more concentrate generally obtaining higher milk yield. This contradicts the findings of Migliorati et al. (2005), where no association was found between milk yield and amount of concentrate fed. To take advantage of the benefits of precision feeding and limit the amount of feed left unconsumed in the AMS feeder after milking, Bach and Cabrera (2017) recommended limiting concentrate allowance in the AMS to < 4 kg/d and 1 to 1.5 kg/visit. Average residual feed (feed not dispensed from the concentrate feeder due to a lack of visits to the AMS) was negatively associated with daily milk yield per cow and per AMS. This contradicts the findings of Tremblay et al. (2016) where a positive association was found between milk yield and average residual feed.

Milking speed had a strong positive association with daily milk yield per cow and per AMS, which indicates that greater milking speeds are associated with an overall increase in the efficiency of the system. Tremblay et al. (2016) also found that milking speed was positively associated with milk yield. Hogeveen et al. (2001) found milking speed (described in their study as milk flow rate) to be positively associated with longer milking intervals. However, greater milking speeds have also been associated with elevated SCC (Slettbakk et al., 1990). Therefore, identifying optimal milking speeds may be more desirable than striving for maximum milking speed to achieve increased AMS efficiency and good cow health.

Treatment time (the time required to prepare the udder for milking and post dip) was negatively associated with both daily milk yield per cow and per AMS. Treatment time averaged 121.8 ± 22.0 sec/cow per milking. Longer treatment time represents less time the AMS is available for milking, which may cause a reduction in number of cows that can be successfully milked with an AMS unit or the frequency at which cows can be milked.

Number of cows/AMS was positively associated with yield per AMS. However, average milk yield per cow/d also had a positive association with cows per AMS. This might indicate that stocking levels per AMS unit in the current study were generally at or below the capacity of the AMS and not exceeding the number of cows the system could successfully handle. It is possible that milk yield/cow per d might be negatively impacted by a higher number of cows/AMS unit. More research is needed to determine the ideal number of cows/AMS unit in U.S. farms in order to optimize the amount of milk produced per cow and per AMS.

CONCLUSIONS

Access to feed on a continual basis by having more frequent feed push-ups appeared to be an important factor to achieve high milk yield in AMS farms. Further work needs to be conducted to evaluate the impact of milking frequency, milking speed and milking time on udder health and milk yield on a per cow and per AMS basis. This information

would help further develop recommendations for improving use of the AMS that will optimize cow health and profitability outcomes for dairy herds. Efforts should continue to be taken to minimize failed milking visits and limit refused visits to the AMS to improve the efficiency of AMS use and increase milk yield.

Chapter 4

Association of parity, stage of lactation, and cow traffic flow with milk yield and milking frequency in automatic milking systems in the Upper Midwest U.S.**SUMMARY**

As more farms adopt automatic milking systems (AMS), it becomes increasingly critical to understand how cows interact with the AMS to allow for the system to be operated efficiently and profitably. Observations from the field have suggested that primiparous cows appear to be less productive in early lactation than would have been expected when using AMS. The objective of this study was to investigate the association between parity (primiparous vs. multiparous cows), stage of lactation and cow traffic flow type (free vs. guided flow) on farms with AMS in the Upper Midwest U.S. Forty farms were included in the study. Stage of lactation was categorized into 14 stages, 7 d in length for the first 28 DIM and 30 d in length thereafter until 328 DIM. Data from lactation days beyond 328 DIM were excluded from the analysis. Cows followed relatively normal trends for lactation curves, with multiparous cows producing more milk than primiparous cows for the majority or all of the lactation period analyzed, and primiparous cows being more persistent in their productivity level by surpassing or approaching the multiparous cows' daily milk yield by the end of the study period. Primiparous cows in free flow systems produced less milk than multiparous cows through the 11th stage of lactation and

produced more milk from the 12th stage until the end of the study period. Primiparous cows in guided flow systems produced less milk than multiparous cows through all 14 stages of lactation, but were approaching the productivity level of multiparous cows at the end of the study period. From 8 to 14 DIM (stage 2), primiparous cows tended to produce more milk in free flow systems than in guided flow systems. Primiparous cows produced more milk in free flow systems than primiparous cows in guided flow systems during stages 3 to 5 (15 to 58 DIM). Multiparous cows in free flow systems produced more milk than multiparous cows in guided flow systems during stage 4, and tended to produce more milk in stages 3, 5, and 6. Both traffic flow systems had lower milking frequency for primiparous cows compared to multiparous cows in early lactation. This lower milking frequency persisted until the 10th stage of lactation in free flow systems, after which primiparous cows were milked more frequently than multiparous cows. In guided flow systems, primiparous cows were milked less frequently until the 5th stage of lactation, had similar milking frequency in the 6th stage of lactation, and were milked more frequently thereafter. Primiparous cows were milked more frequently in free flow systems than guided flow systems during stages 8 through 14, and multiparous cows were milked more frequently in free flow systems from stage 2 through stage 14. These findings appear to indicate a lagging performance for primiparous cows in early lactation as compared to multiparous cows; therefore, additional investigation into improving the adaptation of primiparous cows to AMS in early lactation may be warranted.

INTRODUCTION

Understanding how cows interact with AMS is critical for identifying ways to improve the efficiency of AMS use. Based on field observations, it appears that evaluating aspects of AMS efficiency for primiparous cows as compared to multiparous cows is warranted. Factors of interest in the evaluation of AMS efficiency include daily milk yield per cow and milking frequency. Early research aiming to understand how cows interact with the AMS found that providing concentrate feed as an incentive to entice cows to the AMS station was necessary to achieve acceptable milking frequency rates (Ketelaar-De Lauwer et al., 1999). The opportunity to obtain palatable feed has been shown to be a greater motivator for cows to attend the milking station than the opportunity to be milked, thus relieving pressure on the udder (Prescott et al., 1998). Tremblay et al. (2016) found free flow cow traffic to be associated with greater milk yield per cow compared to guided flow traffic. In free flow cow traffic farms, cows can freely move among the feeding, resting and AMS station areas without guidance by one-way gates to the AMS station or a sorting system that determines if the cow must first be milked before being released to the feeding or resting area. The latter is what happens in a guided flow system. The objective of this study was to compare milk yield and milking frequency of primiparous and multiparous cows at different stages of lactation and managed with either free or guided flow cow traffic systems on AMS farms. Results of this study could then help direct future research to identify AMS management

recommendations that could improve the efficiency of AMS use and cow performance in AMS.

MATERIALS AND METHODS

Forty farms using AMS in the Midwest U. S. (Minnesota and Wisconsin), were enrolled in the current study. Thirty nine farms had Holsteins and 1 farm had Jerseys. These farms used Lely Astronaut (Lely Industries N. V., Maassluis, The Netherlands) or DeLaval VMS (DeLaval International AB., Tumba, Sweden) to milk their cows. Thirty-one of the farms used a free flow cow traffic system and 9 used guided flow cow traffic. All farms in the current study housed their lactating cows in barns with no access to pasture. Approximately 18 mo of daily data for individual cows automatically recorded by each farm's AMS software were collected, including milk yield and milking visits to the AMS station, as well as data on parity and DIM.

Data collected from the software were used to evaluate the interaction of parity, stage of lactation, and cow traffic flow system (free flow cow traffic or guided flow cow traffic) with milking frequency and milk yield. Stage of lactation was categorized into 14 stages: 4 stages, each 7 d in length for the first 28 DIM after calving, a period of rapidly changing milking frequency and acclimation to the milking system, and 10 additional stages, each 30 d in length were used in analyzing data from 29 to 328 DIM. Data

beyond 328 DIM, which is slightly longer than the standard lactation length of 305 days, were excluded from the analysis.

Statistical Analysis

The normality of milk yield and milking frequency data was assessed by univariable analysis (PROC UNIVARIATE, SAS 9.4, SAS Institute Inc., Cary, NC). Data were analyzed using linear mixed models. The model was fit using Proc MIXED (SAS 9.4) with the LSMEANS and PDIFF option used to investigate differences in milk yield (Kg/d) and milking frequency (milkings/d) (the 2 outcome variables in the current study) by parity and traffic flow system within stages of lactation. Fixed effects included the main effects of cow traffic flow, parity, stage of lactation; as well as the interactions of cow traffic flow by stage of lactation, cow traffic flow by parity, stage of lactation by parity, and cow traffic flow by stage of lactation by parity. Farm was used as a random effect. Associations were considered tendencies at $P < 0.1$ and significant at $P < 0.05$.

RESULTS AND DISCUSSION

Milk Yield

We collected 2,858,514 daily cow records for milk yield from the 40 farms enrolled in the current study. The Jersey herd was not excluded from the milk yield analysis because doing so had no significant impact on the interpretation of the results. Stage of lactation,

parity, and the interactions of traffic flow by stage of lactation, traffic flow by parity, stage of lactation by parity, and traffic flow by stage of lactation by parity were associated with milk yield ($P < 0.001$). The main effect of traffic flow type was not associated with milk yield, measured on a Kg/cow per d basis ($P = 0.199$). In free flow systems, primiparous cows produced less milk than multiparous cows from the beginning of lactation through the 11th stage of lactation (238 DIM) and produced more milk from the 12th stage until the end of the study period (239 to 328 DIM). In guided flow systems, primiparous cows produced less milk than multiparous cows through all 14 stages of lactation. Within parity and between traffic flow systems, differences and trends were found during some of the early stages of lactation (Table 5). In all instances where a difference or trend was detected, cows in free flow systems produced more milk than those in guided flow systems. These findings are supported by those of Tremblay et al. (2016), where farms with free flow systems were found to have greater milk yield than those with guided flow systems.

Milking Frequency

We collected 2,858,514 daily cow records for milking frequency (daily visits to the AMS milking station) from the 40 farms enrolled in the current study. In both free and guided flow systems, primiparous cows visited the AMS less frequently than multiparous cows in early lactation (Table 4). In free flow systems, primiparous cows maintained lower milking frequency than multiparous cows through the first 9 lactation stages (178 DIM),

had similar milking frequency during the 10th lactation stage, and subsequently had greater milking frequency for the remainder of the lactation than multiparous cows. Cows in guided flow systems followed a slightly different pattern to those in free flow systems. Primiparous cows maintained lower milking frequency through the first 5 stages of lactation (58 DIM), after which primiparous cows had greater milking frequency or tended to have greater milking frequency through the 10th lactation stage, and had similar milking frequency to multiparous for the remainder of the lactation.

In free flow systems, milking frequency peaked at 2.80 ± 0.04 milkings/d (mean \pm SE) between 119 and 148 DIM for primiparous cows and 3.18 ± 0.04 milkings/d for multiparous cows between 15 and 21 DIM. In guided flow systems, primiparous cows reached peak milking frequency between 59 and 88 DIM with 2.72 ± 0.08 milkings/d, whereas multiparous cows reached peak milking frequency between 15 and 21 DIM with 2.73 ± 0.08 milkings/d.

Primiparous cows managed in free flow systems tended to have higher milking frequency during stage 3 (15 to 21 DIM) and all stages of lactation from 119 DIM until the end of the analysis period, than primiparous cows in guided flow systems. Multiparous cows had greater milking frequency in free flow systems for all stages after 7 DIM than multiparous cows in guided flow systems, except for the 14th stage from 299 to 328 DIM.

It has been well established that cows milked more frequently produce more milk (Amos and Lowenstein, 1985, Erdman and Varner, 1995). In conventional milking systems, Erdman and Varner (1995) found that 3x/d milking was associated with an increase of 3.5 kg/d in milk yield/cow and a 92 g/d increase in fat yield/cow compared to 2x/d milking. This result was independent of the productivity level of the herd. Frequent milking in early lactation has been shown to have positive effects on milk yield, and to have lasting impacts on milk yield when milking frequency is reduced later in lactation. Patton et al. (2006) compared 1x/d and 3x/d milking for the first 28 DIM and 2x/d milking thereafter, and Hale et al. (2003) compared 4x/d milking during the first 21 DIM and thereafter milked 2x/d to 2x/d milking over the entire lactation. Results from both of these studies showed increased frequency of milking in early lactation resulted in increased milk yield that sustained beyond the early lactation period.

A key benefit for many AMS farmers is the ability to increase milking frequency above 2x/d and receiving the benefits of increased milking frequency, without increasing the amount of labor needed for the successful operation of the farm, and potentially reducing the total amount of labor required (Dijkhuizen et al., 1997). Further investigation into the frequency of milking in early lactation in AMS is needed to identify whether the lack of successful milking visits for primiparous cows in early lactation is of concern, and if so what practices may be implemented to increase milking frequency for these individuals.

The differences found in traffic flow systems contradicted the findings of Munksgaard et al. (2011) where no notable differences were detected between milking frequencies, behavior, or number of cows needing to be fetched for milking between free and guided traffic flow. However, it is important to note their study was conducted where the AMS was utilized considerably below capacity (mean of 35 cows/AMS).

CONCLUSIONS

The differences between guided and free flow systems may be influenced by factors other than the system itself, which was not assessed in the current study. Milking permission settings were not obtained from the farms so it is possible this could be one reason for milking frequency difference between guided and free flow systems. More research is needed to evaluate the use of software settings and different management practices to optimize milking frequency of cows in AMS. Further investigation into methods for improving performance of primiparous cows in the first few weeks of lactation that will allow these individuals to express their performance potential during their first lactation are also warranted.

Chapter 5

Association of parity and stage of lactation with number of failed and refused visits to free flow automatic milking systems on dairy farms in the Upper Midwest U.S.**SUMMARY**

As more farms adopt automatic milking systems (AMS), it becomes increasingly critical to understand how cows interact with the AMS to allow for the system to be operated efficiently and profitably. The objective of the study was to investigate the relationship between parity (primiparous vs. multiparous) and stage of lactation with number of failed and refused visits to the AMS. Daily data from the AMS software on 30 farms with free cow traffic flow in 2 states in the Midwest U.S. (Minnesota and Wisconsin) were collected for a period of 18 mo. Stage of lactation was categorized into 6 periods, 7 d in length each for the first 28 DIM, and 150 d in length thereafter until 328 DIM. Data from lactation days beyond 328 DIM were excluded from the analysis. Failed milking visits (when milking units do not attach to the cows even though it was time for them to be milked) were greater for primiparous cows during all stages of lactation; however, the greatest differences of the most relevance, both biologically and from the perspective of herd management in an AMS system, were detected in the early stages of lactation. Primiparous cows had 0.067 more failed milking visits/cow per d than multiparous cows during the 1st week of lactation. For the remaining lactation stages, differences in failed

milking visits ranged from 0.003 to 0.039. Refused visits to the AMS (when cows visited the AMS before adequate time had passed and cows left the AMS milking station without being milked) was less for primiparous cows during the first 2 weeks of lactation, similar for the 3rd week of lactation, and more frequent for the remaining lactation stages. These findings seem to indicate that the performance of primiparous cows in early lactation might be lagging when compared to multiparous cows, therefore additional investigation into improving the adaptation of primiparous cows to AMS in early lactation may be warranted.

INTRODUCTION

Understanding how cows interact with the AMS is critical for identifying ways in which to improve the efficiency of AMS use. Early research aiming to understand how cows interact with the AMS showed that providing feed as an incentive to entice cows to the AMS was necessary to achieve acceptable milking frequency rates (Ketelaar-De Lauwer et al., 1998). The opportunity to obtain palatable feed is a greater motivator for cows to attend the milking station than the opportunity to relieve pressure on the udder (Prescott et al., 1998). Cows that fail to be milked, due to either equipment failure or cow related factors, produce less in the following milking event, on a milk yield/h adjusted basis (Bach and Busto, 2005), and return to be milked sooner, reducing the efficiency of AMS use (Stefanowska et al., 1999). Refused visits result from cows visiting the AMS before sufficient time has passed since their previous milking visit. These refused visits hinder

AMS efficiency, as the milking station is being occupied by a cow that is not ready to be milked rather than being available for cows that are due for milking.

The objective of this study was to investigate the relationship between parity (primiparous vs. multiparous) and stage of lactation with number of failed and refused visits to the AMS. Results of the study might then help direct future research to identify AMS management and facility design recommendations that could improve the efficiency of AMS use and cow performance in AMS.

MATERIALS AND METHODS

Lely Astronaut (Lely Industries N.V., Maassluis, The Netherlands) AMS with free flow cow traffic design were used on the farms included in this study. Cows were housed in barns with no access to pasture on all farms in this study. Approximately 18 mo of data for individual cows automatically recorded by each farm's AMS software were collected, including daily milking visits, failed visits, and refused visits to the AMS, as well as data on parity and DIM.

Stage of lactation was categorized into 6 periods, 7 d in length each for the first 28 DIM, and 150 d in length thereafter until 328 DIM, which is slightly longer than the standard

lactation length of 305 days. Data from lactation days beyond 328 DIM were excluded from the analysis.

Statistical Analysis

The normality of milk yield and milking frequency data was assessed by univariable analysis (PROC UNIVARIATE, SAS 9.4, SAS Institute Inc., Cary, NC). Because these were non-normally distributed variables, frequency of failed and refused visits to the AMS were evaluated using the NLMIXED procedure (SAS 9.4) with a Zero Inflated Poisson model. Starting values for the fixed effect parameters of stage of lactation, parity, and stage of lactation by parity interaction were obtained using the GENMOD procedure (SAS 9.4). The GLIMMIX procedure (SAS 9.4) was used to obtain the starting value for the random effect of cow ID. Associations were considered tendencies at $P < 0.1$ and significant at $P < 0.05$.

RESULTS AND DISCUSSION

Failed Milking Visits

Failed milking visits are characterized as visits to the AMS where the cow should have been milked, however due to equipment failures or the inability of the AMS to attach or reattach the milking unit due to conformation or cooperation issues with the cow, a milking visit was not successfully completed.

Frequency of failed milking visits was different ($P < 0.05$) between primiparous and multiparous cows during all stages of lactation; however the most biologically relevant differences were seen in early lactation (Table 6). During the first 7 DIM, primiparous cows experienced on average 0.067 more failed milking visits/d than multiparous cows. After the first 7 DIM, the difference between primiparous and multiparous cow rates of failed visits/d declined to between 0.039 and 0.002 for the remainder of the lactation stages. The higher frequency of failed milking visits in early lactation for primiparous cows relative to multiparous cows may partially explain the lower milking frequency of primiparous cows in early lactation reported in Chapter 4.

Failed milking visits are problematic for the efficiency of the AMS because not only does the cow leave the AMS without successful completion of milking but she is also slower and more hesitant to leave if she did not receive concentrate (Stefanowska et al., 1999). Following a failed milking event, it was reported cows returned to the AMS sooner compared to successful milking visits (within about 2 h compared to about 5 h), which was attributed to the cow's desire to obtain additional concentrate feed and/or for the completion of milking. Additionally, Bach and Busto (2005) found quarters that experienced milking failure (simulated a milking failure by skipping a milking in a conventional system) produced 26% less milk in the subsequent milking event when adjusted for the extended milking interval, with greater decreases in yield as DIM increased.

Rodenburg (2002) found farms in Ontario with an average of 94 cows experienced 0 to 3 culls per year due to cows failing to adapt to the AMS, primarily because of udder conformation issues (rear teats placed too close together or too high on the rear quarters of the udder). These cows may be detected by the farmer as problems for the AMS early in lactation and be culled from the AMS milked herd, leading to lower average failure rates for cows in later lactation stages.

Although the specific cause of the milking failures was not included in this analysis, the rapid reduction in difference between parities for failed milking visit rates during early lactation might likely be attributed to a combination of factors, which may include the primiparous cows learning how to interact with the AMS to be milked successfully, the AMS's learning of the cow's udder conformation, changes in udder conformation, and culling individuals from the AMS milked herd that are unfit for the system due to udder conformation or other issues. Lely recommends striving for < 5 milking failures/AMS per d (https://www.lely.com/media/filer_public/0a/19/0a19b805-6d5a-4485-9c94-e56496598bc7/lely_kennisdocument_-_management_en.pdf) and estimates each failure to take 8 min of AMS time, therefore 5 failures/AMS per d would equate to approximately 40 min of AMS time/d being consumed by unsuccessful milking events. Jacobs and Siegford (2012) reviewed the literature and reported that attachment failure rates in studies of AMS farms ranged from 2 to 15%, with lower attachment failure rates in more recently conducted studies. This might indicate a recent improvement in AMS

efficiency likely being driven by technological advancements, better management of the herd, and genetic selection for cows with suitable conformation for automatic milking.

Refused Milking Visits

Refused milking visits are the result of a cow approaching the AMS to be milked before adequate time (as determined by the system permission settings) has lapsed since her previous successful milking visit. Primiparous cows had less refused milking visits during the first 2 wk of lactation (stages 1 and 2; Table 7), which might indicate that primiparous cows visited the AMS less frequently relative to the permission settings as compared to multiparous cows. During the 3rd wk of lactation, primiparous cows had a similar number of refused visits to the AMS/d compared to multiparous cows, and after the 3rd wk of lactation, primiparous cows had more refusals than multiparous cows.

These results indicate that primiparous cows were coming to the AMS more often than multiparous cows for the majority of their lactation, relative to the AMS permission settings for these lactation groups. This is in agreement with the findings of King et al. (2017) where it was found cows of lower parity had greater frequency of refused AMS visits than those of greater parity. Previous work has also found frequency of refused milking visits to be negatively associated with number of cows per AMS (King et al., 2017). Frequency of refused milking visits was also lower for lame cows than for those that were not lame (King et al., 2017) and lame cows required being fetched for milking

more frequently due to too long of milking intervals (Bach et al., 2007). Additionally, cows of lower body condition score (≤ 3) had less refused milking visits than those of higher body condition scores (≥ 3.5) (King et al., 2017). Lely recommends a goal of maintaining >1 refusal/cow per d, provided at least about 150 min/d of AMS free time are maintained (https://www.lely.com/media/filer_public/0a/19/0a19b805-6d5a-4485-9c94-e56496598bc7/lely_kennisdocument_-_management_en.pdf). If a dairy farm is experiencing a higher number of refusals than expected, the reason for these refusals should be evaluated, as both positive factors (such as a well-balanced ration or healthy cows), as well as negative factors (such as AMS software settings or lack of feed available in the feed bunk) may be influencing this outcome. Some research has been conducted evaluating the effect of using pre-selection gate systems to limit the number of refused visits to the AMS, therefore potentially allowing for more time in the AMS being allocated toward milking.

CONCLUSIONS

More research needs to be conducted to evaluate the use of AMS permission settings and management practices to minimize failures and limit the number of refused milking visits. Further investigation into methods for improving performance of primiparous cows in the first few weeks of lactation that will allow these individuals to express their performance potential during their first lactation are also warranted.

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APPENDIX I – Tables

Table 1. Least squares means of milk yield per AMS/d and cow/d for categorical variables in 33 farms with AMS on Midwest US dairy farms.

Variable	Least Squares Means (kg)	
	Yield per AMS	Yield per cow
New/retrofit facility		
New	1834.2	32.7
Retrofit	1893.5	33.8
Free stall type		
Mattress	1810.9	31.9
Sand	1950.8	34.9
Waterbed	1960.5	35.0
Manure Handling		
Automatic scraping	1900.3	33.6
Manual scraping	1799.8	33.3
Slatted floor	1862.8	33.9
AMS/pen		
1/pen	1834.5	32.0
>1/pen	1897.2	34.9
Feed push-up		
Automatic feed push-up	2078.1 ^a	36.4 ^a
Manual feed push-up	1726.4 ^b	31.5 ^b
Contained bunk	1894.7 ^{a,b}	33.5 ^{a,b}

^{a,b,c} Means within variables differ ($P < 0.05$).

Table 2. Multivariate analysis of farm-level factors and their association with milk yield per cow (kg/d) on 32 farms using AMS on Midwest US dairy farms.

Variable	Estimate	SE	<i>P</i> -value
Average DIM	-0.00268	0.000534	<.0001
Average age of herd (mo)	0.08883	0.004766	<.0001
Average milking visits to the AMS/cow per day	6.4683	0.06324	<.0001
Average refused visits to the AMS/cow per day	-0.4145	0.02082	<.0001
Average failed visits to the AMS/ cow per day	-0.5476	0.1126	<.0001
Average concentrates fed/cow per day	1.2134	0.02668	<.0001
Average residual feed/cow per day	-3.2611	0.1026	<.0001
Milking speed (L/min)	5.3412	0.05793	<.0001
Milking time (s)	0.06327	0.000513	<.0001
Treatment time (s)	-0.01832	0.000919	<.0001
Cows/AMS	0.007949	0.002071	0.0001

Table 3. Multivariable analysis of farm-level factors and their association with milk yield (kg/d) per automatic milking system (AMS) unit on 32 farms using AMS on Midwest US dairy farms.

Variable	Estimate	SE	<i>P</i> -value
Average age of herd (mo)	10.25	0.29	<.0001
Average milking visits to the AMS/cow per day	328.51	3.85	<.0001
Average refused visits to the AMS/cow per day	-27.11	1.30	<.0001
Average failed visits to the AMS/cow per day	-59.27	7.06	<.0001
Average concentrates fed/cow per day (kg)	63.28	1.67	<.0001
Average residual feed/cow per day (kg)	-165.53	6.43	<.0001
Milking speed (L/min)	295.97	3.63	<.0001
Milking time (s)	3.53	0.03	<.0001
Treatment time (s)	-0.78	0.06	<.0001
Cows/AMS	29.70	0.13	<.0001

Table 4. Milking frequency (AMS visits/d) by traffic flow and parity at different stages of lactation in 40 farms with AMS on Midwest US dairy farms.

Stage of Lactation		Free Flow Systems ¹		Guided Flow Systems ²	
		Primiparous	Multiparous	Primiparous	Multiparous
Stage	DIM	Estimate	Estimate	Estimate	Estimate
1	1-7	2.03 ^a	2.61 ^b	1.94 ^a	2.52 ^b
2	8-14	2.26 ^a	3.14 ^{b,e}	2.15 ^a	2.69 ^{b,f}
3	15-21	2.47 ^{a,g}	3.18 ^{b,e}	2.31 ^{a,h}	2.73 ^{b,f}
4	22-28	2.60 ^a	3.15 ^{b,e}	2.49 ^a	2.70 ^{b,f}
5	29-58	2.68 ^a	3.08 ^{b,e}	2.64 ^a	2.68 ^{b,f}
6	59-88	2.75 ^a	3.04 ^{b,e}	2.72 ^a	2.65 ^{b,f}
7	89-118	2.78 ^a	3.00 ^{b,e}	2.67 ^a	2.58 ^{b,f}
8	119-148	2.80 ^{a,g}	2.94 ^{b,e}	2.59 ^{a,h}	2.51 ^{b,f}
9	149-178	2.79 ^{a,g}	2.86 ^{b,e}	2.47 ^{c,h}	2.45 ^{d,f}
10	179-208	2.76 ^g	2.76 ^e	2.42 ^{a,h}	2.39 ^{b,f}
11	209-238	2.71 ^{a,g}	2.65 ^{b,e}	2.35 ^h	2.35 ^f
12	239-268	2.62 ^{a,g}	2.50 ^{b,e}	2.30 ^h	2.29 ^f
13	269-298	2.46 ^{a,g}	2.34 ^{b,e}	2.23 ^h	2.22 ^f
14	299-328	2.41 ^{a,g}	2.26 ^b	2.18 ^h	2.19

^{a,b} Parity within traffic flow system within stage of lactation differ ($P < 0.05$)

^{c,d} Parity within traffic flow system within stage of lactation tend to differ ($P < 0.1$)

^{e,f} Traffic flow system within parity differ ($P < 0.05$)

^{g,h} Traffic flow system within parity tend to differ ($P < 0.1$)

¹Pooled SE = 0.04; ²Pooled SE = 0.08

Table 5. Milk yield (kg) by traffic flow system and parity at different stages of lactation in 40 farms with AMS on Midwest US dairy farms.

		Free flow system ¹		Guided flow system ²	
Stage of lactation		Primiparous	Multiparous	Primiparous	Multiparous
Stage	DIM	Estimate	Estimate	Estimate	Estimate
1	1-7	16.21 ^a	24.18 ^b	12.77 ^a	23.88 ^b
2	8-14	23.74 ^{a,c}	35.51 ^b	18.01 ^{a,d}	32.92 ^b
3	15-21	26.87 ^{a,c}	39.50 ^b	20.51 ^{a,d}	36.33 ^b
4	22-28	28.85 ^{a,c}	41.94 ^{b,e}	22.44 ^{a,d}	38.21 ^{b,f}
5	29-58	30.97 ^{a,c}	43.55 ^b	24.95 ^{a,d}	40.19 ^b
6	59-88	32.15 ^{a,c}	42.70 ^b	27.09 ^{a,d}	40.04 ^b
7	89-118	32.17 ^{a,e}	40.63 ^b	28.54 ^{a,f}	38.64 ^b
8	119-148	31.83 ^a	38.38 ^b	28.59 ^a	36.92 ^b
9	149-178	31.19 ^a	36.06 ^b	28.07 ^a	34.92 ^b
10	179-208	30.53 ^a	33.77 ^b	27.45 ^a	32.61 ^b
11	209-238	29.62 ^a	31.20 ^b	26.94 ^a	30.19 ^b
12	239-268	28.32 ^a	28.08 ^b	26.16 ^a	27.79 ^b
13	269-298	26.39 ^a	24.96 ^b	24.75 ^a	25.35 ^b
14	299-328	25.41 ^a	22.93 ^b	23.55 ^a	23.73 ^b

^{a,b} values for primiparous vs. multiparous cows within traffic flow system significantly different ($P < 0.05$)

^{c,d} values within parity between traffic flows differ ($P < 0.05$)

^{e,f} trend for difference within parity and stage between traffic flow systems ($P < 0.1$)

¹Pooled SE = 1.01; ²Pooled SE = 1.87

Table 6. Mean count difference of failed milking visits between primiparous and multiparous cows by stage of lactation on 30 AMS farms on Midwest US dairy farms.

Stage	DIM	Estimate	SE	<i>P</i> -value	Lower	Upper
1	1-7	0.0675	0.0006	<.0001	0.0663	0.0686
2	8-14	0.0395	0.00035	<.0001	0.0388	0.0401
3	15-21	0.0257	0.00023	<.0001	0.0252	0.0261
4	22-28	0.0358	0.00032	<.0001	0.0351	0.0364
5	29-178	0.0215	0.00019	<.0001	0.0211	0.0219
6	179-328	0.0029	0.00003	<.0001	0.0029	0.0029

Table 7. Mean count difference of refused milking visits between primiparous and multiparous cows by stage of lactation on 30 AMS farms on Midwest U.S. dairy farms.

Stage	DIM	Estimate	SE	<i>P</i> -value	Lower	Upper
1	1-7	-0.5711	0.00634	<.0001	-0.5836	-0.5587
2	8-14	-0.4129	0.00772	<.0001	-0.428	-0.3978
3	15-21	-0.0116	0.00723	0.1077	-0.0258	0.0025
4	22-28	0.0951	0.00693	<.0001	0.0815	0.1087
5	29-178	0.1158	0.00213	<.0001	0.1117	0.12
6	179-328	0.1358	0.00234	<.0001	0.1312	0.1404

APPENDIX II – Figures

Figure 1. Average daily milk yield per cow per day by farm (kg) on Midwest U.S. dairy farms with automatic milking systems and no pasture access (n=33).

