Farm- and Cow-Level Effects on the Behavioral Patterns of Dairy Cows

Milked with Automatic Systems

by

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ABSTRACT

FARM- AND COW-LEVEL EFFECTS ON THE BEHAVIORAL PATTERNS OF DAIRY COWS MILKED WITH AUTOMATIC SYSTEMS

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The objective of this thesis was to determine the effect of housing and feeding management and cow characteristics on the behavioral patterns of cows in automated milking systems (AMS). In a first study, increasing frequency of feed delivery from 1 to 2x/d for cows milked in an AMS resulted in longer lying duration. In that study, lame cows milked less frequently, had increased lying durations and more frequent lying bouts. In a second, cross-sectional study of 13 AMS farms it was found that cows had longer lying durations when given more space at the feed bunk and when their feed was pushed up more frequently. Milking frequency increased as cows/AMS decreased. Milk yield increased with space at the feed bunk. Overall, these results suggest that feeding management, robot and bunk-space availability, and health status affect the behavior and production of AMS-milked cows.
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CHAPTER 1: INTRODUCTION

With the increasing interest in automated milking systems (AMS) in North America comes the need for evaluation of these systems as they relate to dairy cow behavior and welfare. It is important to recognize the possible changes in cow daily time budgets as they relate to milking system and management. Behavioral patterns have been studied extensively in traditional free-stall parlor systems (Overton et al., 2002; DeVries and von Keyserlingk, 2005), but there are still many questions and more research to be done in regards to AMS.

Proper feed bunk management is extremely important when managing nutrition in a free-stall barn. All cows must have access to the feed bunk at peak feeding times to receive the proper ration and to promote milk production. For dairy herds with AMS, the distribution of milking events is spread over a 24-h period. Previous research has found less synchrony in the behaviors of cows milked with AMS (Winter and Hillerton, 1995). It has been suggested that since the flow of animals to the feed bunk in AMS is different than the slug effect of cows accessing it with conventional parlor systems, the feed bunk space requirements for cows in an AMS may be less than the industry norm of 0.61 m per cow (Grant and Albright, 2001; Wagner-Storch and Palmer, 2003).

Standing and lying behavior patterns are of great interest from a health, productivity, and welfare standpoint. Dairy cows are highly motivated to lie down for approximately 12-13 h/d (Jensen et al., 2005; Munksgaard et al., 2005). The time cows have available for eating and lying can be affected by barn conditions and their social environment, for instance crowding (Wierenga and Hopster, 1990; Leonard et al., 1996;
Fregonesi et al., 2007) or a long waiting time for access to milking (Ketelaar-de Lauwere et al., 1996; Gomez and Cook, 2010). A cow’s lying behavior is influenced by production and health status (Fregonesi and Leaver, 2001; Walker et al., 2008). Additionally, standing duration, particularly post-milking standing durations, can influence udder health (DeVries et al., 2010, 2011). Previous research has indicated that it is beneficial for cows to remain standing after milking to help prevent an intramammary infection (Peeler et al., 2000). It is common practice to keep cows standing following milking to allow the teat end to close sufficiently before possibly encountering a soiled stall where her risk for an environmental mastitis infection would increase (McDonald, 1975; Schultze and Bright, 1983).

Free stall barns are the most commonly-used style of barn for housing cows milked with AMS units. While there are many advantages to this style of housing, including ease of cleaning and feeding, these benefits are often countered by shortcomings in terms of cow health. Herd owners are faced with a multitude of choices to make when building a new barn, including stall base and surface types, style and length of the feed bunk, and flooring type. Several researchers have reported higher rates of lameness in free-stall herds compared with tie-stall herds (Wells et al., 1993; Bergsten and Herlin, 1996; Cook, 2003). This result suggests that there are differences in environmental conditions between the two systems that are important to the epidemiology of lameness. These may include differences in hoof hygiene, factors that influence free stall access, and differences in cow behavior relative to stall use (Cook et al., 2004). Lameness is of great concern to dairy producers with AMS not only due to the
fact that the cows must be able to get up and visit the feed bunk, but more importantly they must be mobile enough to go get milked in the AMS unit.

This review will, therefore, explore different aspects of housing and feeding management and lameness and how these affect the behavioral patterns of dairy cows milked with AMS.

1.1 Time Budget of Dairy Cows

The time budget of dairy cows can be broken into several major categories: milking, eating, drinking, resting, socializing in alleys and standing in stalls (Gomez and Cook, 2010). In the majority of housing systems in North America, where cows are housed in a free-stall setting and go to a parlor to be milked, they have little control over time spent in the parlor facilities. In AMS systems, cows decide when to visit the robot, but may wait a period of time to access the milking unit (Jacobs et al., 2012). Cows are highly motivated to lie down for 12 to 13 h/d in confinement housing (Jensen et al., 2005; Munksgaard et al., 2005). Lying is a higher priority behavior than eating and social contact when opportunities to perform these behaviors are restricted (Munksgaard et al., 2005). Cows on pasture display a negative relationship between lying time and milk yield (Castle and Halley, 1953). This is due to the fact that high-producing cows have higher energy requirements than low yielding cows, requiring them to be grazing for longer time throughout the day, and as a consequence have less time available to lie down (Castle and Halley, 1953). Similarly, Fregonesi and Leaver (2001) and DeVries et al. (2011) found that high-yielding cows housed indoors have shorter lying times but longer feeding times than low-yielding cows. In a tie-stall study, where cows have ample access to both feed and lying, high-yielding cows still stood for longer periods of time (Norring et al., 2012).
When not in the free stalls lying, cows spend a large portion of their time eating (17 to 25%) (Fregonesi et al., 2004; Uzal and Ugurlu, 2010). Drinking and socializing in alleys take up a very small portion of the time budget of the cow at about 2% and <1% respectively (Fregonesi et al., 2004; Uzal and Ugurlu, 2010).

1.2 Feeding behavior and Feed Bunk Management

Cattle, in a grazing environment, display diurnal feeding patterns where the majority of their daily dry matter intake (DMI) is consumed during the daytime (Hafez and Boissou, 1975). More specifically, cows have been referred to as crepuscular feeders; consuming the largest meals at sunrise and sunset (Ray and Roubicek, 1971; Hafez and Boissou, 1975; Ruckebusch and Bueno, 1978). Cows housed intensively indoors have similar feeding patterns to grazing cattle. Both free-stall and tie-stall housed cows tend to eat the majority of their daily intake during the day with peak feeding times occurring immediately following milking and feeding (Tanida et al., 1984; Haley et al., 2000; Wagner-Storch and Palmer, 2003). Additionally, Wagner-Storch and Palmer (2003) reported cows having greatest feeding activity during the day in AMS-milked cows.

There are multiple influences on feeding behavior including feeding system design and apparatus, composition and physical characteristics of feed consumed, social hierarchy, and competition for food and water (Grant and Albright, 2000; DeVries et al., 2003).

In conventional systems, it is common for cows to be herded from the pen as a group to be milked and then to feed as a group upon their return from milking, particularly when fresh feed is available at the bunk (DeVries and von Keyserlingk, 2005). The industry standard for linear space at the feed bunk has traditionally been considered 0.61 m/cow (Grant and Albright, 2001). When cows are managed under this
industry standard, fewer than 70% of animals feed simultaneously at peak times (DeVries et al., 2003). This suggests that space availability limits animals from feeding together, especially during popular eating times. If feeding space is limited, increased competition among cows at the feed bunk may lead to some cows modifying their feeding times to avoid aggressive interactions (Miller and Wood-Gush, 1991). When comparing parlor and AMS, Wagner-Storch and Palmer (2003) observed that there was a more consistent flow of animals to the feed bunk in the AMS farms than in the conventional systems. In addition to providing more space at the feed bunk (DeVries et al., 2004), one way to make feed more available to subordinate cows in a free stall setting is to increase frequency of fresh feed delivery. DeVries et al. (2005) demonstrated that, not only does increased frequency of feed delivery allow for more animals to access fresh feed throughout the day, it also increases daily feeding time. This could be important for cows in AMS that are milking throughout the day, promoting them to remain standing for a time after milking. Additionally, this may not only be beneficial for udder health, but also improve cow traffic, resulting in greater milking frequency, more consistent milking intervals and fewer fetched cows. These lower, more consistent percentages of cows eating at one time could suggest that less linear feed bunk space per cow is required on AMS farms (Morito et al., 2000; Wagner-Storch and Palmer, 2003).

1.3 Standing and Lying Behavior

Research suggests that dairy cows spend approximately 12-13 h/d lying and are highly motivated to maintain this amount of rest (Fregonesi et al., 2007). There are many benefits to resting, some of these include potentially greater milk synthesis due to greater blood flow through the udder and greater blood flow to the gravid uterus during late
lactation (Nishida et al., 2004). Dairy cows can prioritize resting over other behaviors (Munksgaard et al., 2005) and cows that are prevented from lying down show behavioral and physical stress responses (Munksgaard and Simonsen, 1995; Fisher et al., 2002). The movements a cow makes to lie down and stand up are affected by the physical environment, such as the lying surface and stall dimensions (Endres and Barberg, 2007). For example, we know that cows prefer to lie on well-bedded surfaces. For each additional kilogram of bedding, cows spend 3 and 12 minutes a day more time lying down for shavings and straw, respectively (Tucker et al., 2009). The diurnal daily pattern of lying in dairy cows is variable and influenced by milking and feeding management (Overton et al., 2002; Devries and von Keyserlingk, 2005). DeVries et al. (2005) demonstrated that increases in feeding time, with increased frequency of feed delivery, resulted in no change in total daily lying time. Thus, with the increased frequency of feed delivery, cows actually make better use of their time standing by eating rather than idly waiting for feed or access to the feed bunk (DeVries et al., 2005). Not only does increasing the frequency of feed delivery have a positive effect on standing behavior, it also allows cows of all ranks to have adequate time at the feed bunk (DeVries et al., 2005). Despite this knowledge for cows milked in conventional systems, it is still not known how frequency of feed delivery affects cows in an AMS.

Researchers have shown that promoting longer standing time in cows following milking is associated with lower herd somatic cell counts (Peeler et al., 2000; Barnouin, et al., 2004). It is common practice to keep cows standing following milking to allow the teat end to close sufficiently before possibly encountering a soiled stall where her risk for an environmental mastitis infection would increase (McDonald, 1975; Schultze and
Bright, 1983). For tie-stall housed dairy cows, the provision of feed around milking time (between 20 min prior and 60 min post) has been shown to result in the longest post-milking standing time (DeVries et al., 2010). Additionally, feed manipulation (delivery of fresh feed or feed push-up) near the time of milking (1 h before, 2 h after) for AMS-milked cows has been shown to result in the longest post-milking standing times (DeVries et al., 2011). DeVries et al. (2011) found that cows that lie down between 100 and 135 min post milking have a lesser chance of acquiring a new intramammary infection than cows that lie down before that. Additionally, cows lying for more than 150 min post milking have greater odds of getting a new intramammary infection. This parallels our knowledge that the teat sphincter diameter increases immediately post milking and again 2-4 h post milking (McDonald, 1975). DeVries et al. (2011) speculated that the cows who spend long periods of time standing after milking, who are at greater risk of acquiring intramammary infections, may be dirtier than the rest of the cows. It is possible that these cows in free stall systems are walking around and possibly splashing manure up onto their teats and therefore, increasing their chances of acquiring a new intramammary infection.

1.4 Lameness

Recent estimates report 20 to 30% of lactating dairy cows in North America are clinically lame (Cook, 2003; Espejo et al., 2006), with the highest rates observed in free-stall herds (Cook, 2003; Haskell et al., 2006; Cook and Nordlund, 2009). Regular monitoring of hoof health is important as the majority of lameness cases are due to hoof lesions (Murray et al., 1996). A cross-sectional study performed in Ontario, Canada, reported high incidences (46.4% of cows sampled) of foot lesions in free-stall systems
(Cramer et al., 2008). Fortunately, there is an increased interest to better monitor and prevent severe cases of lameness by using locomotion scoring systems (Espejo and Endres, 2007). Systems like this evaluate certain walking behaviors and postures that are associated with lameness; typically cows are scored on a scale of 1-5 with 1 being sound and 5 being severely lame (Sprecher et al., 1997; Flower and Weary, 2006). In addition to scoring systems, abnormal lying behavior has proven to be a good predictor of lameness risk and may aid in risk factor identification on dairy farms (Dippel et al., 2009). Some of these abnormal lying behaviors include: interrupted lying down and rising movements, lying down or rising lasting longer than 20 seconds, reversed lying, horse-like rising and dog-like sitting (Gonzalez et al., 2008).

Next to mastitis, lameness is a top animal health and welfare concern in the dairy industry. Farmers undergo an incredible economic loss due to lameness from premature culling, reduced milk yield, weight loss, reduced fertility, and decreased slaughter value (Sprecher et al., 1997; Warnick et al., 2001). Walker et al. (2008) demonstrated that lame cows dedicate less time to standing and walking as a consequence of lying down more. In addition to altered lying behavior, cows with increased locomotion disorders decrease feed intake (Gonzalez et al., 2008). This is especially important for cows milked in AMS where they must be motivated and capable to go to the milking unit by themselves. Fetching of cows for milking is a management procedure, characteristic for most AMS herds, which can cause an increased workload on the farm staff. It has been found that lameness reduces the number of voluntary milkings per day (Grove et al., 2003; Klaas et al., 2003); leading to more human assisted milkings if milking interval and fetching criteria are maintained. Rodenburg (2008) reported that 15% of the cows needed to be
fetched by the producers. The primary reasons why cows needed to be fetched in that study were lameness and mastitis.

Free stall barns are most commonly used in AMS. In terms of hoof health, free stall barns are more detrimental to hoof health than tie-stall or open pack barns (Cook, 2003; Fregonesi et al., 2009), and have the highest rates of lameness (Cook and Nordlund, 2009). Herd-level risk factors for lameness within free stall-housed cows include stall features (Espejo and Endres, 2007), lying surface (Cook, 2003; Espejo et al., 2006), overcrowding (Leonard et al., 1996), increased time spent away from the pen milking (Espejo and Endres, 2007) and the use of automatic alley scrapers (Barker et al., 2007).

Foot and leg disorders cause pain in the cow and standing causes discomfort (Whay et al., 1998) therefore it is no surprise that standing time is greatly reduced with the onset of lameness (Hassall et al., 1993). The ability and freedom to lie down and rest at ease are important for dairy cattle welfare (Endres and Barberg, 2007). Even though lameness is a constant problem on most dairies, early identification is difficult. With decreasing human-animal interaction through larger herds, feeders that limit personnel requirements, and the implementation of AMS, early identification of lame cows is becoming more problematic (Frost et al., 1997; Gonzalez et al., 2008). It is important to consider lameness in AMS, especially when the common housing system used, free stall barns, is highly correlated with hoof and leg problems. More research needs to be conducted to help us better understand the best housing, bedding, and feeding management practices for AMS in terms of production for producers, while maintaining high standards of cow comfort and minimizing lameness.
1.5 AMS

With the introduction of AMS, the daily routine of a dairy herd changes markedly. Instead of going to a parlor to be milked, the cows must go to the AMS on a voluntary basis several times per day. Milking frequency is determined by both the cows’ motivation to attend the AMS and the farmers’ criteria for desired interval between milkings. Dairy farms utilizing AMS strive for high milking frequencies. By increasing milking frequency from 2 to 3 times per day, an increase in milk yield from 6 to 25% per lactation is observed (Amos et al., 1985; DePeters et al., 1985; Allen et al., 1986; Klei et al., 1997), and there is also a decrease in SCC (Hogeveen et al., 2001). There are two common setups for AMS barns; forced-cow traffic, where the AMS is the only route from the lying area to the feeding area; or free-cow traffic, where the cows do not have to visit the AMS in order to get to feed (Ketelaar-de Lauwere et al., 1998). Milking frequency has been shown to differ between free-cow traffic and forced-cow traffic systems. Researchers have previously suggested that greater milking frequency can be obtained with forced-cow traffic (2.5 to 2.9 milkings/d) compared with free-cow traffic systems (2.0 to 2.2 milkings/d) (Melin et al., 2007; Bach et al., 2009). However, Castro et al. (2012) observed an average of 2.7 milkings/d and another observational study reported an average of 2.5 milkings/d for free-cow traffic AMS units (Gygax et al., 2007). Madsen et al. (2010) reported 3.0 milkings/d in a free-cow traffic system, indicating a greater cow throughput of the AMS is possible in this system.

In AMS, availability of the robot is of concern when trying to maximize milking frequencies, primarily due to the fact that milking interval is known to have significant effect on milk yield (Hogeveen et al., 2001). Milk yield, milking frequency, and milking
interval are all important functional aspects of an AMS (Gygax et al., 2007). It has been found that the cows’ motivation to visit the AMS unit is relatively low; therefore cows are enticed to attend by feed concentrates (Prescott et al., 1998; De Koning and Rodenburgh, 2004; Van’t Land et al., 2000). High-producing cows in particular may receive a high proportion of concentrates during milking in the AMS, causing them to go to the milking machine more frequently (Klaas et al., 2003). Consequently, in another study, low-yielding cows did not significantly increase their level of attendance when fed at the AMS, suggesting that the feed was insufficient in itself to increase the motivation of low-yielding cows to visit the AMS (Prescott et al., 1998). The difference in milking intervals or frequency may best be explained by cow-related factors, such as their motivation to be milked, their social dominance in the group, their udder pressure, milk yield, parity and health status (Nixon et al., 2009).

If milking frequency is very low as a result of lameness, it can indicate a welfare problem in these cows: they may be hungry and less likely to visit the feed bunk and also may refrain from visiting the AMS (Klaas et al., 2003). The computer system connected to the AMS alerts the farmer to cows that have exceeded the defined maximum milking interval. These cows are often ‘fetched’ for milking by the farmer. Fetching of cows for milking is a management procedure characteristic for most AMS herds and is responsible for a significant workload on the individual farm (Rousing et al., 2005). Researchers have demonstrated that lameness reduces the number of voluntary milkings per day (Grove et al., 2003; Klaas et al., 2003), leading to more human assisted milkings if milking interval and fetching criteria are maintained. In addition to lameness, milking frequency can be influenced by milk yield (Caja et al., 2000), stocking rate at the AMS, palatability of the
concentrate, social stress (low ranking cows), mastitis, injured udder or teat, poor teat placement, cow inexperience, fear of the AMS, or other diseases inhibiting locomotion (Klaas et al., 2003; Rodenburg, 2008). Increasing the frequency of feed delivery and feed push-up may not only entice cows to feed and use the AMS but could also allow lame cows to access the feed bunk with less competition.

**Objectives and Hypotheses**

The overall objective of this thesis was to determine the effect of housing and feeding management and cow characteristics on the behavioral patterns of cows in automated milking systems (AMS). This objective was addressed in two separate studies. The objective of the first study (Chapter 2) was to determine the effect of frequency of feed delivery on the behavioral patterns of dairy cows milked in AMS. A secondary objective in this first study was to determine how this effect is influenced by lameness. It was hypothesized that an increase in frequency in feed delivery from 1 to 2x/d would promote longer post milking standing durations and that we might see more lame cows with longer standing durations due to increased feeding activity with feed being made more available. The objectives of the second study (Chapter 3) were to describe the housing and feeding management and cow characteristics (parity and stage of lactation), of commercial AMS dairies and their association with the behavioral patterns and productivity of lactating dairy cows. In this observational study it was hoped that further knowledge about current management practices and their association with cow behavior would provide insight to producers of how these practices can be implemented to optimize productivity and welfare.
CHAPTER 2: EFFECT OF FREQUENCY OF FEED DELIVERY ON THE BEHAVIORAL PATTERNS OF DAIRY COWS MILKED IN AN AUTOMATIC SYSTEM

2.1 INTRODUCTION

It has been well-documented that the behavioral patterns of cows are affected by feeding management. Management factors such as grouping, feeding system design and apparatus, composition and physical characteristics of feed, as well as social hierarchy and competition for food and water, all influence feeding behavior in cattle (Grant and Albright, 2000). Traditionally, producers have delivered fresh feed around milking time to promote cows to remain standing after milking. This approach has been supported by various studies in free-stall housed cows (Tyler et al., 1997; DeVries and von Keyserlingk, 2005). The idea behind this practice is that keeping cows standing after milking will allow the teat orifice to close before contacting a soiled stall upon the cow’s lying down, decreasing the odds of acquiring a new intramammary infection. A study by DeVries et al. (2010) explored this idea in tie-stall housed cows and found that the provision of feed around milking time (30 min prior to and 60 min after milking) resulted in the longest post-milking standing times. Furthermore, to our knowledge, this may be one of the first studies to document how post-milking standing time relates to the risk of intramammary infection (IMI). As predicted, those cows that lay down on average for the first time 40-60 min after milking had lower odds of a new environmental IMI compared to cows that lay down within 40 min after milking. In a follow-up study by DeVries et al. (2011), it was found that post-milking standing times in cows milked with an AMS were greater when cows milked near the time of delivery of fresh feed or feed push-up. In AMS, milkings occur throughout the day, leading to unpredictable milking patterns,
therefore, the provision of fresh feed at multiple time points throughout the day may entice cattle to go feed and remain standing following milking rather than lie down. This may not only be beneficial for udder health, but also improve cow traffic, resulting in greater milking frequency, more consistent milking intervals and fewer fetched cows. Little is known, however, about how frequency of feed delivery influences the behavioral patterns of cows milking in an AMS.

Aside from mastitis, lameness is a primary health and welfare concern for the dairy industry, especially on AMS farms. In conventional systems, lame cows may dedicate less time to standing and walking as a consequence of lying down more (Walker et al., 2008; Ito et al., 2010). Additionally, increased incidence of locomotion disorders negatively impacts feed intake (Gonzalez et al., 2008) and milk yield (Warnick et al., 2001; Green et al., 2002; Bicalho et al., 2008). Studies performed in AMS have indicated that lameness reduces the number of voluntary milkings per day (Grove et al., 2003; Klaas et al., 2003), leading to more human assisted milkings, particularly if milking interval and fetching criteria are maintained. Lame cows also spend less time feeding (Gonzalez et al., 2008) and perform fewer aggressive interactions (Galindo and Broom, 2002) than non-lame cows. Thus, in an AMS where it is imperative cows have the ability to attend the AMS and feed bunk themselves, lameness is of great concern.

The primary objective of this study was to determine the effect of frequency of feed delivery on the behavioral patterns of dairy cows milked in AMS. Our secondary objective was to determine how this effect is influenced by lameness. It was hypothesized that an increased frequency in feed delivery would promote longer post milking standing times.
2.2 MATERIALS AND METHODS

2.2.1 Farm Description

A study was conducted from May to July of 2010 with 90 lactating Holstein dairy cows on a commercial dairy farm (Williamsburg, ON, Canada), kept in 1 of 2 groups. The herd was comprised of 122 cows split into 2 groups, 90 of which were used for the study. Each group contained 60 and 62 cows, respectively, over the study period. Complete data were obtained from 47 and 43 animals within each respective group, as some cows were dried off during the course of the experiment. At the beginning of the experiment, cows were 178 ± 83 DIM (range = 23 to 326) and had an averaged parity of 2.0 ± 1.1 lactations (range = 1 to 6) for pen 1; and were 168 ± 87 DIM (range = 24 to 423) and had an averaged parity of 2.1 ± 1.9 lactations (range = 1 to 10). Cows were housed in 2 symmetrical pens in a free stall barn (see DeVries et al., 2011) separated by a drive-through feed alley; with each pen containing an AMS (Astronaut A2, Lely Industries, NV, Maassluis, The Netherlands). Pens were arranged for free cow traffic to the AMS. Each pen contained 60 free stalls in a 2-row configuration. The two rows of stalls faced one another, were open at the front, and had a bed length of 2.55 m. All free stalls measured 1.20 m wide, and the neck rail was 1.14 m above the stall bedding surface. Stalls were deep bedded with 0.40 m of sand. Stalls were cleaned and raked daily and new bedding was added weekly. There was rubber flooring on the crossover alleys and on the 2.0 m space in front of the length of the feed bunk, the rest of the floor space was grooved concrete. In each pen there was a post-and-rail feed barrier with 0.81 m/cow of feeding space and 3 water troughs (each 1.8 m x 0.5 m; length x width). Cows were provided 18 h of continuous light per day; each day, barn lights automatically turned on
at 0430 h and turned off at 1030 h. Cows had access to the AMS for 23 h per day (a 20-
min wash occurred at 0130, 1240, and 1800 h each day). Cows were allowed to access
the AMS after 6 h from the previous milking, unless a milking failure occurred, in which
case the cow would immediately be allowed permission to be milked again. Cows for
which more than 12 h elapsed since the last milking were fetched and brought to the
AMS at 0500 and 1700 h each day.

All animals received mixed ration at the feed bunk as well as supplemental
concentrate at the AMS. The mixed ration was formulated according to the NRC (2001)
nutrient requirement recommendations for high-producing dairy cows. The ration
consisted of (on a DM basis) 25.2% corn silage, 34.6% haylage, 21.6% high moisture
corn, 9.5% protein and mineral supplement, 6.9% roasted soybeans, and 2.2% wheat
straw. Cows received varied amounts of concentrate in the AMS (2.0 to 5.5 kg/d) based
on the individual cow milk production and stage of lactation. The amount of concentrate
apportioned at each milking was based on the elapsed time since the previous milking.

### 2.2.2 Experimental Treatments and Design

Cows within each group were exposed to each of 2 treatments in a cross-over
design with 35-d periods. Treatments were: 1) delivery of TMR 1x/d (at 0730 h), and 2)
delivery of TMR 2x/d, (at 0730 and 1730 h). Throughout both treatments, feed was
pushed 3x/d at approximately 0445 h, 1515 h, and 1945 h.

### 2.2.3 Standing and Lying Behavior

Standing and lying behavior was recorded during the last 7 d of each treatment
period. Standing and lying behaviors were collected using data loggers (HOBO Pendant
G Data Logger, Onset Computer Corporation, Pocasset, MA). This device measured leg orientation at 1 min intervals, and allowed all the standing and lying behavior data to be collected electronically (Ledgerwood et al., 2010). Prior to utilization, care was taken to synchronize the times of the AMS and the data loggers. These devices were attached to one of the hind legs of the cows using veterinary bandaging tape (Vetrap Bandaging Tape, 3M, London, ON, Canada). Data collected were used to calculate standing and lying duration (min/d), bout frequency (#/d), and bout length (min/bout). Duration of post-milking standing (min) was calculated as the difference in time between the end of milking and the first recorded instance when the cow lay down following milking. Duration of pre-milking standing (min) was calculated as the difference in time between the start of milking and the time at which the cow stood up prior to milking.

2.2.4. Animal and Management Data

All individual-cow milking data, including daily milking frequency, time of each milking, and yield per milking were automatically collected and stored by the AMS. Lameness and hygiene scoring of the study cows were performed by two trained researchers, which validated themselves for repeatability and reliability, on days 18 and 35 of each period. Lameness was scored using a 5-point numerical gait scoring system (1 = sound to 5 = severely lame) devised by Flower and Weary (2006). A score of 1 was given to a cow with smooth and fluid movement, a score of 2 for imperfect locomotion but the ability to move freely was not diminished, a score of 3 for a cow that was capable of locomotion but the ability to move freely was compromised, a score of 4 for a cow whose ability to move freely was obviously diminished, and a score of 5 for a cow whose ability to move was severely restricted and had to be vigorously encouraged to move.
Cow cleanliness was assessed using a hygiene scoring system (www.vetmed.wisc.edu/dms/fapm/fapmtools/4hygiene/hygiene.pdf; Cook and Reinemann, 2007). Using this system, cows were scored on a 4-point cleanliness scale, individually evaluating the udder, lower legs, and upper legs-flank (1 = very clean to 4 = very dirty). During the weeks while standing and lying behavior of the cows was being monitored, the daily times of feed delivery and feed push-up were recorded by the herd manager. The time delay between milking time and the closest-in-time feed manipulation (feed delivery or push up) was calculated.

2.2.5 Statistical Analysis

Prior to analyses, all data were screened for normality using the UNIVARIATE procedure of SAS (SAS Institute, 2008). The lameness data was skewed, with a higher percentage of cows scoring a 1 or 2. All data were summarized across the last 7 d of each treatment period for each cow. To determine the effects of frequency of feed delivery treatment, lameness, lactation and days in milk (DIM) on lying duration, frequency of lying bouts, lying bout length, pre-milking standing duration, post-milking standing duration, milking frequency, milk yield, and cow cleanliness (lower leg, udder, and upper leg), a multivariable mixed model was fitted to the data using the MIXED procedure of SAS (SAS Institute Inc., 2009). The models included the random effects of cow within group, group, and period. Univariable analyses were conducted for the fixed effects of treatment, lactation, DIM, lameness, lying duration, frequency of lying bouts, lying bout length, pre-milking standing duration, post-milking standing duration, milking frequency, milk yield, and cow cleanliness (lower leg, udder, and upper leg) to determine which explanatory variables had an effect on the outcome variable being evaluated. Asides from
treatment, which was always kept in the model, only those variables with associations with \( P < 0.25 \) in this initial screening were included in the multivariable linear regression model (Dohoo et al., 2009). The CORR procedure of SAS was used to check for correlations between the retained explanatory variables. If two variables were highly correlated \((r > 0.8)\), the one with the lower \( P \)-value in the univariable analysis was kept. Manual backward elimination of non-significant \((P > 0.1)\) effects were used and, from the resultant models, plausible 2-way interactions were examined and retained if \( P \leq 0.1 \).

### 2.3 RESULTS AND DISCUSSION

Descriptive statistics for the study cows, their behavior and hygiene, are found in Table 2.1. Cows averaged 2.6 ± 0.6 milking/d, which is slightly higher than what has been found in other AMS free-cow traffic systems (2.4 milking/d, Wagner-Storch and Palmer, 2003; 2.2, Bach et al., 2009). Milk yield data (Table 2.1) were comparable to a previous study performed on the same farm by DeVries et al. (2011) who observed an average milk yield of 32.6 ± 9.4 kg/d. This yield was higher than that reported in an observational study consisting of 8 AMS farms in which the 578 cows had an average milk yield of 29.6 ± 8.7 kg/d (Borderas et al., 2008).

There is limited empirical data on duration of resting behavior in AMS. Lying duration observed in the current study (Table 2.1) was similar to that observed by DeVries et al. (2011) on the same AMS farm (11.2 ± 2.5 h/d). DeVries et al. (2011) noted that it was interesting to find, in their study, that AMS-milked cows had similar resting behavior to conventional parlor-milked free-stall housed cows (Wechsler et al., 2000; Cook et al., 2005; Ito et al., 2009). Previous work has found that cows housed in well-designed free-stall facilities lie down for about 12 h/d (Cook et al., 2004). Our data,
coupled with the resting behavior findings of DeVries et al (2011) and Deming et al. (in preparation), suggest that AMS cows housed in free-stall facilities, typically lie down for about 12 h/d. While there are limited reports on lying bout length and duration in AMS-milked cows, lying bout length and duration were comparable to that observed by DeVries et al. (2011).

Average pre-milking and post-milking standing durations are found in Table 2.1. In contrast to other free-stall studies (with parlor-milking systems: 35 min, Tyler et al., 1997; 55 min: DeVries and von Keyserlingk, 2005; 62 min, DeVries et al., 2005), average post-milking standing duration in the current study was longer. The average pre-milking and post-milking standing durations in the current study were closer to what DeVries et al. (2011) observed in an AMS herd; 94 min and 78 min, respectively, and what Deming et al. (in preparation) observed in a survey study of 13 AMS herds; 103 min and 75 min, respectively.

Lameness data are found in Table 2.1; these scores were right skewed; the median score was 1. The majority of the herd (61%) was given a lameness score of 1; with 30% being scored a 2, and with only 9% scoring a 3 or 4; none of the cows were given a score of 5. Previous observational studies have reported higher prevalence of slightly to severely lame cows in free-stall systems than that found in the current study. Borderas et al. (2008) reported 20% of cows in AMS herds to be slightly to severely lame (≥ 3) using the Flower and Weary (2006) lameness scoring system. Espejo et al. (2006), using a combination of the Sprecher et al. (1997) and O’Callaghan et al (2003) lameness scoring systems, reported a prevalence of 24.6% cows being lame (≥ 3) in free-stall, conventionally-milked herds.
Cows fed 2x/d milked in the AMS closer in time (SE = 15.6; P < 0.001) to a feed delivery, milking on average 67.5 min from a feed delivery, while when fed 1x/d, cows milked in the AMS at time points much further away from feed delivery (199.0 min). DeVries et al. (2011) found that when cows went to the AMS to be milked close to the time of a feed manipulation, it resulted in cows remaining standing post-milking to engage in some sort of feeding activity. Their results suggested that post-milking standing duration of cows milked with an AMS can be increased by providing fresh feed, as well as by pushing up feed more frequently throughout the day. Knowing that feed delivery is such a strong stimulant for cows to go and feed, particularly around milking time (Tyler et al., 1997; DeVries and von Keyserlingk, 2005; DeVries et al., 2010; 2011), our objective was to see if feeding 2x/d would have a similar effect on post-milking standing behavior for cows milked in AMS. In the current study, cows fed 1x/d stood for 9.3 min longer after milking than did cows that were fed 2x/d (Table 2.2). DeVries et al. (2005) similarly found, for free-stall housed, parlor-milked cows, that increasing the frequency of feed delivery resulted in cows spending less time standing after milking. Those researchers suggested that cows were spreading their feeding time more evenly throughout the day when fed more frequently, and not having as many large single feeding events, particularly after milking.

We found that lying duration tended to increase when cows were fed 2x/d (Table 2.2). Contrary to this, in a study of free-stall housed, parlor-milked cows, DeVries et al. (2005) found, that increasing the frequency of feed delivery resulted in no change in daily lying duration. In a survey study of AMS herds by Deming et al. (in preparation), it was found that while frequency of feed delivery was not associated with longer lying
durations, lying duration increased with greater frequency of feed push-ups. In that study, it was speculated that when feed is more available to the cows (Endres and Espejo, 2010), they can be more efficient in their feeding behaviors, dedicating more time to eating rather than inactive standing, allowing more time to lie down (DeVries et al., 2005).

Regardless of treatment, cows spent more time lying down and had more frequent lying bouts with increased lameness scores (Table 2.2). The association between lameness and longer lying duration (Singh et al., 1993; Juarez et al., 2003; Ito et al., 2010), along with lameness and longer lying bouts (Chapinal et al., 2009; Ito et al., 2010) have previously been documented. Foot and leg disorders cause pain for the cow and standing results in discomfort (Whay et al., 1998), possibly causing standing time to be reduced with the onset of lameness (Hassall et al., 1993). In the current study, total daily lying duration was also longer for cows of greater DIM (Table 2.2). This finding is supported by previous research that have indicated that total daily lying time is longer in late lactation cows, when milk yield is usually lower, than early lactation cows when milk yield is at its highest (Hasegawa et al., 1993; Chaplin and Munksgaard, 2001; Norring et al., 2012). Prior to the study conducted by Norring et al. (2012), it had been speculated that cows earlier in lactation have a greater energy requirement and are thus lying less due to increased time standing at the feed bunk. However, Norring et al. (2012) found that there was not an association between time constraints due to eating and its effect on the lying behavior of high-yield cows, suggesting there may be other factors than time constraints due to eating contributing to the decrease. It is possible that stage of pregnancy is affecting lying behavior. Cows usually conceive during early lactation, and the increased days in gestation may affect cow lying behavior (Nishida et al., 2004).
We did not find associations between frequency of feed delivery and milking frequency or milk yield (Table 2.3; Figure 2.1). Furthermore, we did not find an association between milk yield and lameness. Contrary to our findings, it is widely accepted that lameness is associated with a reduction in milk yield (Juarez et al., 2003; Bicalho et al., 2008; Archer et al., 2010). However, due to the fact that previous research has indicated that lame cows eat fewer, faster meals than non-lame cows, while consuming similar amounts of feed (Gonzalez et al., 2008), it could be hypothesized that the lame cows in the current study were still able to consume enough feed as to not hinder milk production. Additionally, the majority of cows had a lameness score of 1 or 2, which is not considered lame, so it is possible the low prevalence of lameness may have played a role in this outcome. The only association found with milk yield was DIM, with cows farther into lactation having the lower milk yield, following a normal lactation curve (Table 2.3). In the current study, we noticed a tendency for cows to milk less frequently when they had a higher lameness score (Table 2.3). This is supported by observational AMS studies by Klass et al. (2003) and Borderas et al., (2008), who both observed that the frequency of milkings per day was significantly influenced by lameness: healthy cows were more likely to have greater milking frequency. One study suggested that lameness is one of the most important factors affecting milking frequency when a relationship between cow mobility and voluntary milking frequency was observed (Spöndly and Wredle, 2002).

Descriptive statistics on cow hygiene are found in Table 2.1. DeVries et al. (2011) considered the possibility that those cows that remain standing for too long periods of time post milking (> 2.5 h), who are at greater risk of IMI, may be dirtier due to spending
more time walking around in a free-stall setting. We had hypothesized that increased feed delivery frequency would result in cows standing longer (while possibly eating), especially after milking, and that these cows may end up dirtier as a result. However, in the current study, we found no associations between hygiene scores or longer standing durations and frequency of feed delivery. Our analysis demonstrated an association between lower leg hygiene and DIM: cows earlier in lactation had poorer lower leg hygiene (Table 2.4). While we did not measure individual cow feed intake, previous research has demonstrated that the onset of lactation in dairy cows after parturition is usually accompanied by a dramatic increase in feed intake (Forbes, 1995). Due to the fact that cows earlier in lactation also lay down for a shorter amount of time than cows later in lactation, it is possible that these cows became dirtier on their legs because they may have been walking around and spent more time standing in manure while at the feed bunk.

In general, lame cows spend more time lying down compared with non-lame cows (Singh et al., 1993; Walker et al., 2008; Chapinal et al., 2009). In the current study, lame cows had poorer hygiene of the upper legs; lame cows also tended to have poorer udder hygiene than non lame cows. Stall cleanliness was not scored during this study, but it is possible that lame cows that were spending more time lying down, also spent more time in soiled stalls, causing their udders and upper legs to become dirtier.

2.4 CONCLUSIONS

Despite having less of an incentive to remain standing, cows still spent more time standing after milking when fed 1x/d. We found that daily lying duration tended to increase when feed was delivered 2x/d. We did not find associations between frequency of feed delivery and milking frequency or milk yield. Regardless of treatment, cows spent
more time lying down and tended to have more lying bouts with increased lameness. Cows with higher lameness scores also tended to milk less frequently. Finally, there was an association between lame cows and poorer hygiene of the upper legs and udders than non lame cows. Overall, the results suggest that frequency of ration delivery has some affect on the behavior of AMS-milked cows. Further, the results show that regardless of frequency of feed delivery, these behavioral patterns are affected by lameness. It would be beneficial for AMS producers to make feed as available as possible to the cows through increased frequency of feed delivery to promote longer lying durations. Additionally, producers should to strive to reduce the occurrence of lameness in their herds to optimize milking frequencies.

2.5 ACKNOWLEDGEMENTS

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research was also supported through contributions from the Canadian Foundation for Innovation (Ottawa, ON, Canada) and the Ontario Research Fund (Toronto, ON, Canada).
Table 2.1. Descriptive statistics for cow level measurements

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity</td>
<td>2.1</td>
<td>1.5</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>DIM(^1)</td>
<td>175</td>
<td>85</td>
<td>23</td>
<td>423</td>
</tr>
<tr>
<td>Milking frequency (#/d)</td>
<td>2.6</td>
<td>0.6</td>
<td>1</td>
<td>5.3</td>
</tr>
<tr>
<td>Milk yield (kg/d)</td>
<td>34.7</td>
<td>8.7</td>
<td>6.1</td>
<td>58.2</td>
</tr>
<tr>
<td>Lying duration (h/d)</td>
<td>10.9</td>
<td>2.0</td>
<td>5.1</td>
<td>16.7</td>
</tr>
<tr>
<td>Lying bouts (#/d)</td>
<td>7.1</td>
<td>2.3</td>
<td>1.8</td>
<td>15.2</td>
</tr>
<tr>
<td>Lying bout duration (min/bout)</td>
<td>100</td>
<td>33</td>
<td>35</td>
<td>223</td>
</tr>
<tr>
<td>Post-milking standing duration (min)</td>
<td>91</td>
<td>53.7</td>
<td>22</td>
<td>421</td>
</tr>
<tr>
<td>Pre-milking standing duration (min)</td>
<td>99</td>
<td>45.5</td>
<td>30</td>
<td>298</td>
</tr>
<tr>
<td>Lameness score(^2)</td>
<td>1.5</td>
<td>0.7</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Hygiene scores(^3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lower leg</td>
<td>3.0</td>
<td>0.6</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Udder</td>
<td>2.0</td>
<td>0.9</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Upper leg</td>
<td>1.9</td>
<td>0.8</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

\(^1\)DIM = days in milk at the beginning of each data collection period

\(^2\)Lameness scores are on a scale of 1 = sound to 5 = severely lame

\(^3\)Hygiene scores are on a scale of 1 = clean to 4 = very dirty
<table>
<thead>
<tr>
<th>Variable</th>
<th>Lying duration (h/d)</th>
<th>Lying bout frequency (#/day)</th>
<th>Lying bout length (min/bout)</th>
<th>Post-milking standing time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta^1$</td>
<td>SE</td>
<td>$P$</td>
<td>$\beta$</td>
</tr>
<tr>
<td>Intercept</td>
<td>9.05</td>
<td>0.63</td>
<td>&lt;0.001</td>
<td>7.6</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1x/d</td>
<td>-0.11</td>
<td>0.2</td>
<td>0.06</td>
<td>-0.04</td>
</tr>
<tr>
<td>2x/d</td>
<td>Ref</td>
<td>-</td>
<td></td>
<td>Ref</td>
</tr>
<tr>
<td>DIM$^2$</td>
<td>0.01</td>
<td>0.003</td>
<td>0.04</td>
<td>-0.01</td>
</tr>
<tr>
<td>Lactation</td>
<td>0.18</td>
<td>0.12</td>
<td>0.13</td>
<td>-</td>
</tr>
<tr>
<td>Lameness</td>
<td>0.4</td>
<td>0.19</td>
<td>0.03</td>
<td>0.3</td>
</tr>
</tbody>
</table>

$^1\beta$ = estimated regression coefficient

$^2$DIM = days in milk at the beginning of each observation period

Ref = Reference category
**Table 2.3.** Final general linear model of the associations of AMS data and explanatory variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Milk yield (kg/d)</th>
<th>Milking frequency (#/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta^1$</td>
<td>SE</td>
</tr>
<tr>
<td>Intercept</td>
<td>44.6</td>
<td>1.9</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1x/d</td>
<td>-0.48</td>
<td>0.49</td>
</tr>
<tr>
<td>2x/d</td>
<td>Ref</td>
<td>-</td>
</tr>
<tr>
<td>DIM$^2$</td>
<td>-0.06</td>
<td>0.01</td>
</tr>
<tr>
<td>Lameness</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

$^1\beta =$ estimated regression coefficient

$^2$DIM = days in milk at the beginning of each observation period

Ref = Reference category
Table 2.4. Final logistic model of the associations of hygiene scoring and explanatory variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lower leg</th>
<th>Udder</th>
<th>Upper leg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta^1$</td>
<td>SE</td>
<td>$P$</td>
</tr>
<tr>
<td>Intercept</td>
<td>3.4</td>
<td>0.22</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Treatment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1x/d</td>
<td>-0.09</td>
<td>0.08</td>
<td>0.27</td>
</tr>
<tr>
<td>2x/d</td>
<td>Ref</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lameness</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DIM$^2$</td>
<td>-0.002</td>
<td>0.001</td>
<td>0.005</td>
</tr>
</tbody>
</table>

$^1\beta$ = estimated regression coefficient

$^2$DIM = days in milk at the beginning of each observation period

Ref = Reference category
Figure 2.1 Relative frequency of cows milking in the AMS unit across the 7 d data collection period.
CHAPTER 3: ASSOCIATIONS OF HOUSING, MANAGEMENT, PRODUCTIVITY AND BEHAVIORAL PATTERNS OF DAIRY COWS MILKED IN AUTOMATIC SYSTEMS

3.1 INTRODUCTION

The time budget of a lactating dairy cow housed in a free-stall environment can be split into seven main categories: milking, eating, lying/resting, ruminating, socializing in alleys, drinking, and standing in stalls (Grant and Albright, 2000). Poorly designed or mismanaged housing facilities can alter normal social interactions, interfere with lying behavior, and result in longer standing times (Greenough and Vermunt, 1991; Singh et al., 1993; Bickert and Cermak, 1997). For instance, overcrowded barns (Wierenga and Hopster, 1990; Leonard et al., 1996; Fregonesi et al., 2007) and long waiting time for access to milking (Ketelaar de Lauwere et al., 1996; Gomez and Cook, 2010) have been known to affect the time cows have available for eating and lying behaviors. Cooper et al. (2007) observed no difference in milk production when lying behavior was restricted for 2 and 4 h, however, Metz (1985) demonstrated that lying is an extremely important activity for cows and when both lying and eating are prevented simultaneously, cows will choose to lie rather than feed. Additionally, Munksgaard et al. (2005) determined that lying is a higher priority than eating and social contact when opportunities to perform these behaviors are restricted. While it has been found that cows housed intensively indoors express less synchronization of behavior than cows housed on pasture (Miller and Wood-Gush, 1991), in conventional dairy systems, synchronization has been observed in some of the daily activities of the herd. For dairy herds with automated milking systems (AMS), the distribution of milking events is spread over a 24-h period. Previous research
has found less synchrony in the behavior of cows milked with AMS, with decreased time spent lying down (Winter and Hillerton, 1995).

In conventional systems, it is common for cows to leave the pen as a group to be milked and then to feed as a group upon their return from milking, particularly when fresh feed is available at the bunk (DeVries and von Keyserlingk, 2005). When cows are managed under the industry standard of 0.6 m of feed bunk space per cow, fewer than 70% of animals feed simultaneously at such peak times (DeVries et al., 2003). This suggests that space availability limits animals from feeding together, especially during popular eating times. If feeding space is limited, increased competition among cows at the feeder may lead to some cows modifying their feeding times to avoid aggressive interactions (Miller and Wood-Gush, 1991). If cows are not able to feed during the desired feeding times (when fresh feed is delivered), there is a possibility that with feed sorting, the subordinate animals are not receiving the same ration as the dominant animals. Sorting of the diet that has been fed can lead to inconsistent ration consumption (Stone, 2004) and reduce nutritive value of the TMR remaining in the feed bunk, particularly in the later hours past the time of feed delivery (DeVries et al., 2005). One way to make feed more available to subordinate cows in a free-stall setting is to increase frequency of fresh feed delivery. DeVries et al. (2005) demonstrated that not only does increased feed delivery frequency allow for more animals to access fresh feed throughout the day, but it also increases daily feeding time.

When comparing parlor and automatic milking systems, Wagner-Storch and Palmer (2003) observed that there was a more consistent flow of animals to the feed bunk in the AMS farms than in the conventional systems. These lower, more consistent
percentages of cows eating at one time could suggest that less linear feed bunk space per
cow is required on AMS farms (Morita et al., 2000; Wagner-Storch and Palmer, 2003).

In AMS, availability of the robot is of concern when trying to maximize milking
frequencies, primarily due to the fact that milking interval is known to have a significant
effect on milk yield (Hogeveen et al., 2001). Milk yield, milking frequency, and milking
interval are all important functional aspects of an AMS (Gygax et al., 2007).

Thus, the objective of this study was to describe the housing and feeding
management of commercial AMS dairies and their association with the behavioral
patterns and productivity of lactating dairy cows. For housing we focused on cow
characteristics (parity and stage of lactation), the space allowances at the feed bunk
(m/cow), free stalls (stalls/cow), and AMS (cows/AMS), as well as the design of the feed
bunk. For feeding management we focused on the frequencies of feed delivery and feed
push-ups.

3.2 MATERIALS AND METHODS

3.2.1 On-farm Data Collection

This cross-sectional observational study was performed on 13 automated milking
system (AMS) farms, in Ontario (Canada), in July and August 2011. Of the farms, 10
milked with an Astronaut (Lely Industries N.V., Maassluis, the Netherlands), and 3
milked with a VMS (DeLaval, International AB, Tumba, Sweden). Herd sizes averaged
71 ± 30 lactating cows, and utilized either 1 (n = 11) or 2 (n = 2) AMS units. Dairy farms
were selected randomly from a list of AMS herds situated within a geographical area
wherein a large proportion of the AMS dairy farms in Ontario are located (southwestern
Ontario). Herd owners were contacted by phone and asked about their willingness to participate in the study. The only criterion for enrollment was that the cows were housed in free-stall barns setup for free-cow traffic to the AMS. All farms had Holstein cows as the predominant breed, but this was not a criterion for selection.

A random sample of 30 cows/herd was selected to monitor standing and lying behavior and milking activity for 4 consecutive d. Ito et al. (2009) demonstrated that reliable estimates of lying behavior on commercial dairy farms can be generated using 3 d of continuous recordings (at 1-min intervals) from 30 focal animals. During those days all milking events (including time, length, frequency, and yield) were automatically collected and electronically stored by the AMS. The cows were 144 ± 92 DIM and had parities of 2.3 ± 1.2 at the beginning of the data collection period. Data on cow parity and DIM were also recorded from the AMS software. Standing and lying behaviors were collected using data loggers (HOBO Pendant G Data Logger, Onset Computer Corporation, Pocasset, MA). This device measures leg orientation at 1-min intervals, and allows all the standing and lying behavior data to be collected electronically (Ledgerwood et al., 2010). Prior to utilization, care was taken to synchronize the times of the AMS and the data loggers. Data loggers were attached to 1 of the hind legs of the cows using veterinary bandaging tape (Vetrap Bandaging Tape, 3M, London, ON, Canada) and recorded for the 4 d. Data collected were used to calculate standing and lying times (min/d), bout frequency (#/d), and bout length (min/bout). Post-milking standing time (min) was calculated as the difference in time between the end of milking and the first recorded instance when the cow lay down following milking. Pre-milking standing time (min) was calculated as the difference in time between the start of milking
and the time at which the cow stood up prior to milking. During the 4 d of data collection, times of feed delivery and feed push-up were recorded by the herd manager. These data were used to record frequencies of feed delivery and feed push-up.

On the initial visit to each farm, when data loggers were attached to the cows’ legs, a survey was administered on farm where facility design and management were measured. On-farm measurements included space allowance at the feed bunk (m/cow), stalls (stalls/cow), and AMS unit (cows/AMS). Style of feed bunk (flat surface or bunk) and feed barrier (post and rail or headlock bunk) were also recorded.

3.2.2 Statistical Analysis

Prior to analyses, all data were tested for normality using the UNIVARIATE procedure of SAS (SAS Institute, 2008). All data were summarized across each of the 4-d collection period for each cow. To determine the effects of housing and management (frequency of fresh feed delivery, frequency of feed push-ups, type of feed bunk, linear feed bunk space, space allowance at the free stalls, and number of cows per robot) and cow characteristics (parity, DIM) had on milking (frequency and yield), standing, and lying behavior, a multivariable mixed model was fitted to the data using the MIXED procedure of SAS (SAS Institute Inc., 2009). The models included the random effects of farm and cow within farm. Univariable analyses were conducted for the fixed effects of parity, DIM, frequency of feed deliveries, frequency of feed push-ups, type of feed bunk, linear feed bunk space, space allowance at the free stalls, stocking density at the AMS, measures of standing and lying behavior, and frequency of milkings and milk yield to determine which explanatory variables had an effect on the outcome variable being evaluated. Only those variables with associations with $P < 0.25$ in this initial screening
were included in the multivariable linear regression model (Dohoo et al., 2009). The CORR procedure of SAS was used to check for correlations between the kept explanatory variables. If two variables were highly correlated, the one with the lower P-value in the univariable analysis and/or the one with the most biologically plausible relationship was kept. Manual backward elimination of non-significant (P > 0.05) and non-trending (P > 0.10) fixed effects was used and from the resultant models, plausible 2-way interactions were examined and retained if P ≤ 0.05.

3.3 RESULTS AND DISCUSSION

Descriptive statistics for the study farms are found in Table 3.1. Farms, on average, had low stocking at the free stalls and slightly higher than recommended space availability at the feed bunk (0.61 m/cow, Grant and Albright, 2001). A previous cross-sectional survey study found that the majority of free-stall dairy farms, milking with parlors, in Minnesota provided 0.45 ± 0.11 m (range = 0.21 to 0.75 m) of feed bunk space per cow, well below industry recommendations (Endres and Espejo, 2010). Previous research has shown that lactating dairy cows experience less competition and improved access to feed when they are provided with more than the industry standard of 0.61 m of feed bunk space per animal (DeVries et al., 2004; Huzzey et al., 2006; DeVries et al., 2006). Even though it has been suggested that feed bunk requirements for cows milked with an AMS may be less than the standard 0.61 m/cow due to less synchronization of feeding activity (Morita et al., 2000; Wagner-Storch and Palmer, 2003), there is little research to support this. There is, in fact, limited data on current feed bunk space availability on AMS farms, and more research is thus needed in this area. It is widely accepted that having nearly 60 cows/AMS unit is the optimal maximum stocking density.
In the current study, it was found that the average number of cows/AMS on the study herds was below this recommended standard (Table 3.1).

Across farms and the 4-d data collection period, 46% of the farms fed once daily, 38% fed twice daily, and 15% fed 3 times daily (Table 3.1). Castro et al. (2012) reported once daily feeding frequencies in their observational study of 29 AMS farms. Bell et al. (2011) observed AMS farms that fed with conventional feeding systems fed, on average, 1.4 ± 1.0 times/d and that those with automated feeding systems provided fresh feed 7.4 ± 1.7 times/d. Again, even though there is little empirical data to support this, Rodenburg (2002) suggested that providing fresh TMR several times per day (particularly in forced cow traffic systems) could be done to improve voluntary visits to the milking unit.

Four of the farms had fixed feed bunks where feed push-up was not necessary. Of the 9 remaining farms, 1 farm averaged 2 feed push-ups per day and 8 of the farms averaged more than 2 feed push-ups per day across the 4-d data collection periods (Table 3.1). There is limited observational data on the frequency of feed push-ups on AMS farms or recommendations for such frequencies. In a survey study of conventionally-milked free stall farms in Minnesota, Endres and Espejo (2010) observed an average of 5.4 ± 2.3 feed push-ups daily.

There is limited data on duration of resting behavior in other studies of AMS herds. In the current study, lying duration (Table 3.2) was similar to that observed by DeVries et al. (2011) in an AMS herd where they reported lying duration of 11.2 ± 2.5 h/d. Cows in the current study, who did not have to stand waiting in a conventional restricted holding area prior to milking, had similar lying times to reports of cows in
parlor-milking, free stall systems (Wechsler et al., 2000; Cook et al., 2005; Ito et al., 2009). In conventional parlor-milking, free stall systems, cows are restricted to a holding area prior to milking. The cows in the current study were not subjected to a restricted holding area, but nevertheless had similar lying durations, where we hypothesized they would have longer lying durations. While data on the AMS waiting area (open area in front of the milking stall) were not documented in the current study, Jacobs et al. (2012) reported that there are multiple factors concerning the holding area that cause cows to hesitate to enter the AMS and may cause cows to stand waiting for longer periods of time to access the AMS. It is possible the AMS holding area has a similar effect on the standing time of the cows as parlor holding pens in conventional systems. Lying bout frequencies and lengths are also found in Table 3.2. Average bout frequency and duration in the current study were similar to what DeVries et al. (2011) observed in an AMS herd (8.0 ± 2.9 bouts/d; 84.1 ± 38.4 min in length). There is a shortage of data on the average duration of lying bouts and bout frequencies of cows in AMS herds.

Similar to previous research of cows milked in a tie-stall system, (Chaplin and Munksgaard, 2001), greater lying duration was associated with cows being later in lactation (Table 3.3). We also found that total daily lying duration was increased with greater frequency of feed push-ups as well as increased space at the feed bunk. Researchers have previously indicated that increased frequency of feed push-ups has little impact on feed bunk attendance and therefore a low impact on feeding activity (DeVries et al., 2003); however, it is possible that with feed being pushed up more frequently, feed is more readily available in the bunk (Endres and Espejo, 2010). Additionally, it has been demonstrated that when more space is available to cows at the feed bunk, they can
dedicate more time to eating, eat in a more efficient time manner (with less inactive standing in the feeding area) (DeVries and von Keyserlingk, 2006), and direct more of their time to lying down (DeVries et al., 2005). Additionally, with more feed bunk space, cows may encounter fewer animals at the feed bunk and, therefore, be subjected to fewer aggressive interactions (DeVries and von Keyserlingk, 2006). Further studies in which feeding behavior is measured would be needed to confirm this hypothesis. This also may be indicative of why lying bout duration increased with increased space at the feed bunk.

It is interesting to note that the majority of the farms enrolled on this study were understocked at the feed bunk. It is possible that barns that had ample space allowances at the feed bunk were built with the intention of future expansion that they have not yet achieved. Whereas, it is possible that farms that had barns that had been converted to accommodate an AMS were designed for fewer animals and had lower space allowances at the feed bunk.

Average pre-milking and post-milking standing durations are found in Table 3.2. Average post-milking standing duration in the current study (75 min) was longer than that previously reported for conventionally-milked free-stall-housed cows (35 min: Tyler et al., 1997; 55 min: DeVries and von Keyserlingk, 2005; 62 min: DeVries et al., 2005). The findings from our study support the reports for cows housed and milked in tie-stalls (79 min; DeVries et al., 2010). More research is needed to better understand why these variations in post-milking standing time between milking systems may be occurring.

Previous research has indicated that it is beneficial for cows to remain standing after milking to help prevent an intramammary infection (Peeler et al., 2000). The reason behind this is that keeping cows standing after milking will allow time for the teat canal
to close, limiting the chance of bacteria penetrating the teat and infecting the udder should she lie down in a soiled stall (McDonald, 1975; Schultze and Bright, 1983). Conversely, it has also been shown that cows that remain standing for over 1.5 h after milking in a tie-stall system, and over 2.5 h in a free-stall AMS system, also have an increased risk of a new udder infection caused by environmental bacteria (DeVries et al., 2010; 2011). It has been hypothesized that there is a second period of increased teat canal diameter (following the initial period that occurs immediately after milking), and thus bacterial penetrability, occurring after 2 h following milking (McDonald, 1975; Schultze and Bright, 1983). In a previous AMS study, post-milking standing duration increased with cows that were exposed to increased frequency of feed delivery and when feed was pushed up frequently (DeVries et al., 2011); however, in the current study, we did not find post-milking standing behavior to be affected by increased frequency of feed delivery. We did find that pre-milking standing time was negatively correlated with frequency of feed push-ups (Table 3.3). This may, again, relate to the hypothesis that feed is more available to the cows with increased frequency of feed push-ups and they may choose to lie down rather than actively search for food. In the current study, post-milking standing behavior was associated with parity (Table 3.3); cows of greater parity spent more time standing following milking. To our knowledge, this may be the first report of such an association. It is possible that older cows likely produce more milk, have higher metabolic demands, and thus remain standing to eat more. In our model, however, milk yield was not a predictor of post-milking standing duration. This would, therefore, suggest that there is likely another factor influencing this phenomenon that we have not captured; more research is thus needed to address this finding.
Across herds, cows averaged 2.8 ± 0.4 milkings/d (Table 3.2). Compared to other studies and reports of milking frequencies in AMS, this observed milking frequency was high. The closest observed milking frequency was an observational study of free-cow traffic AMS farms in which Castro et al. (2012) observed an average of 2.7 ± 0.3 milkings/d. Another observational study reported an average of 2.5 milkings/d for free-cow traffic AMS units (Gygax et al., 2007). Other non-observational studies have reported milking frequencies ranging from 2.2 to 2.5 milkings/d (Wagner-Storch and Palmer, 2003; Bach et al., 2009). However, Madsen et al. (2010) reported 3.0 milkings/d in a free-cow traffic system, indicating a greater cow throughput of the AMS is possible. Interestingly, researchers have previously suggested greater milking frequency with forced-traffic (2.5 to 2.9 milkings/d) compared with free-traffic systems (2.0 to 2.2 milkings/d) (Melin et al., 2007; Bach et al., 2009); however, all of the herds enrolled on this study were of free-traffic systems and still had relatively high milking frequencies.

Milk yield data can be found in Table 3.2. An observational study by Castro et al. (2012) observed an average of 28.5 ± 3.9 kg/d for AMS cows in free cow traffic systems. Greater milk yield was associated with cows having more space at the feed bunk (Table 3.4). There are very few studies in both conventional and AMS systems concerning feed bunk space availability and milk production. Naess et al. (2011) reported that there is no evidence that feed bunk space has any significant effect on milk yield both in conventional parlor systems and AMS. It has been documented that reducing feed bunk space has a negative effect on feeding behavior for free-stall housed cows milked in conventional parlors (Friend et al., 1977; DeVries et al., 2004), most notably affecting low-ranked cows (Huzzey et al., 2006). There is evidence supporting dry matter intakes
(DMI) being positively correlated with milk yield in conventional milking systems (Martin and Sauvant, 2002) and the importance of formulating rations with appropriate DMI for AMS-milked cows has been noted by Halachmi et al. (2011). It is possible that more space at the feed bunk resulted in higher milk yields because cows may be encountering fewer aggressive interactions at the feed bunk and having the chance to increase DMI (DeVries and von Keyserlingk, 2006). However, it should be noted that neither herd- nor cow-level DMI were recorded in this study.

In the current study, greater milking frequency was associated with lower stocking density at the AMS (Table 3.4). Availability of the AMS is an important factor when trying to maximize milking frequencies (Hogeveen et al., 2001). Jacobs et al. (2012) found that even in under-stocked AMS farms, cow behavior and group dynamics may influence the availability, efficiency, and overall success of the AMS. Additionally, those researchers speculated that when the AMS is at full capacity, the largest influence on AMS time budgets could be social dynamics within groups of cows or individual variation in behavior. In robotic systems, it is recommended that cows frequent the AMS as much as possible to optimize successful milking visits. Similarly to that observed by Gygax et al. (2007), cows in this study had a higher milking frequency in early lactation than cows later in lactation. This, coupled with our finding of decreased milk yield with increased DIM, may suggest that visits to the AMS closely reflect the change in milk yield throughout lactation. Also in agreement with previous research by Bach et al. (2009), cows with higher parities had fewer milkings. Work by Spolders et al. (2004) supports the findings from the current study that multiparous cows visit the AMS less frequently than primiparous cows, and that milk yield is higher for multiparous cows. We
encourage more research to better understand the association of higher parity and fewer milkings in AMS.

3.4 CONCLUSIONS

In this observational study we found that cows milked in AMS herds in Ontario milked more frequently when they were of lower parity, were of fewer DIM, and experienced lower stocking density at the AMS. We also saw positive associations between providing more space at the feed bunk and increased feed push-ups with overall daily lying time. Additionally, there was a positive association between increased space at the feed bunk and milk yield. From this study, we can conclude that increased milking frequency may be achieved on AMS farms by keeping space allowance at the robot in the lower range. Further, in AMS systems, greater milk yield and lying duration may be achieved by ensuring cows have ample feed bunk space and have their feed readily available to them in the bunk. Further studies concerning feed bunk space allowance and feed intake of both subordinate and dominant animals would be useful.

3.5 ACKNOWLEDGEMENTS

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Table 3.1. Descriptive statistics of feeding and housing management of 13 AMS herds in Ontario

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency of feed delivery (#/d)</td>
<td>1.6</td>
<td>0.8</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Frequency of feed push-up (#/d)</td>
<td>2.1</td>
<td>1.6</td>
<td>0</td>
<td>5.5</td>
</tr>
<tr>
<td>Space allowance at AMS&lt;sup&gt;1&lt;/sup&gt; (cows/AMS)</td>
<td>55</td>
<td>11</td>
<td>34</td>
<td>71</td>
</tr>
<tr>
<td>Space allowance at free stall (cows/free stall)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.9</td>
<td>0.1</td>
<td>0.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Feed bunk space (m/cow)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.7</td>
<td>0.2</td>
<td>0.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

<sup>1</sup>Measures taken on first day of data collection period on each farm
Table 3.2 Descriptive statistics of the production and behavior variables across 13 AMS herds in Ontario

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parity</td>
<td>2.3</td>
<td>0.5</td>
<td>1.4</td>
<td>3.2</td>
</tr>
<tr>
<td>DIM$^1$</td>
<td>144</td>
<td>34</td>
<td>93</td>
<td>209</td>
</tr>
<tr>
<td>Milkings frequency (#/d)</td>
<td>2.8</td>
<td>0.4</td>
<td>2.3</td>
<td>3.8</td>
</tr>
<tr>
<td>Milk yield (kg/d)</td>
<td>35.1</td>
<td>10</td>
<td>9.8</td>
<td>68</td>
</tr>
<tr>
<td>Lying duration (h/d)</td>
<td>10.8</td>
<td>1.2</td>
<td>9.3</td>
<td>13.9</td>
</tr>
<tr>
<td>Lying bouts (#/d)</td>
<td>9.3</td>
<td>3.1</td>
<td>2.3</td>
<td>25.8</td>
</tr>
<tr>
<td>Lying bout length (min/bout)</td>
<td>78.1</td>
<td>28.2</td>
<td>29.1</td>
<td>270.9</td>
</tr>
<tr>
<td>Post-milking standing time (min)</td>
<td>75</td>
<td>20</td>
<td>34</td>
<td>110</td>
</tr>
<tr>
<td>Pre-milking standing time (min)</td>
<td>103.4</td>
<td>35.5</td>
<td>52</td>
<td>185.8</td>
</tr>
</tbody>
</table>

$^1$DIM = days in milk at the beginning of each observation period
Table 3.3 Final general linear model of the associations of standing and lying behavior with explanatory variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Lying time (h/d)</th>
<th>Lying bout length (min/bout)</th>
<th>Pre milking standing time (min)</th>
<th>Post milking standing time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>β</td>
<td>SE</td>
<td>P</td>
<td>β</td>
</tr>
<tr>
<td>Intercept</td>
<td>7.48</td>
<td>0.73</td>
<td>&lt;0.001</td>
<td>48.97</td>
</tr>
<tr>
<td>DIM¹</td>
<td>0.004</td>
<td>0.001</td>
<td>0.001</td>
<td>0.035</td>
</tr>
<tr>
<td>Parity</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Frequency of feed push-up (#/d)</td>
<td>0.43</td>
<td>0.118</td>
<td>0.004</td>
<td>-</td>
</tr>
<tr>
<td>Feed bunk space (m/cow)</td>
<td>2.84</td>
<td>1.12</td>
<td>0.03</td>
<td>36.69</td>
</tr>
</tbody>
</table>

β = estimated regression coefficient

¹DIM = days in milk at the beginning of each observation period
Table 3.4 Final general linear model of the associations of AMS data with explanatory variables

<table>
<thead>
<tr>
<th>Variable</th>
<th></th>
<th>Milk yield</th>
<th></th>
<th></th>
<th></th>
<th>Milkings</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>β¹</td>
<td>SE</td>
<td>P-value</td>
<td></td>
<td>β</td>
<td>SE</td>
<td>P-value</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td></td>
<td>26.56</td>
<td>3.70</td>
<td>&lt;0.001</td>
<td>4.42</td>
<td>0.51</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIM²</td>
<td></td>
<td>-0.049</td>
<td>0.004</td>
<td>&lt;0.001</td>
<td>-0.003</td>
<td>0.0004</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Parity</td>
<td></td>
<td>1.9</td>
<td>0.031</td>
<td>&lt;0.001</td>
<td>-0.055</td>
<td>0.028</td>
<td>0.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robots (cows/AMS)</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-0.02</td>
<td>0.0088</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed bunk space (m/cow)</td>
<td>16.87</td>
<td>5.32</td>
<td>0.01</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹β = estimated regression coefficient.

²DIM = days in milk at the beginning of each observation period
CHAPTER 4: GENERAL DISCUSSION

4.1 Important Findings

In our first study (Chapter 2), increasing the frequency of feed delivery from 1 to 2x/d for AMS milked cows did not promote longer post-milking standing durations. Previous research in AMS and non-AMS herds has demonstrated that post-milking standing behavior can be increased through more frequent delivery of feed. In the current study, cows that were fed 1x/d had longer post-milking standing durations than cows fed 2x/d. We also found that daily lying durations tended to increase when cows were fed 2x/d. With these two findings, we hypothesize that when feed is made more available, through increased frequency of feed delivery, cows are probably feeding more efficiently. Thus, they can then dedicate more of their time to lying down, which we presume to be beneficial for lactating dairy cows. As expected, delivery of fresh feed 2x/d resulted in cows milking in the AMS closer in time to a feed delivery than cows fed 1x/d. We did not find any associations between frequency of feed delivery and milking frequency or milk yield. Additionally, contrary to what we expected, milk yield was not associated with lameness. We did, however, find a tendency for cows to milk less frequently when they had higher lameness scores. There was also an association between higher lameness scores and increased frequency of lying bouts per day. Finally, cows of higher DIM had greater lying bout lengths.

While our results did not indicate an association between cow hygiene and frequency of feed delivery, we did observe associations between higher lameness scores and poorer hygiene of the upper legs and udders. It is probable that the cows that are lame are lying down longer, possibly in soiled stalls, causing poorer hygiene scores.
Additionally, cows that were earlier in lactation had poorer leg hygiene and lay down for shorter amounts of time than cows later in lactation. It is possible the lower leg hygiene of these cows was poorer due to longer standing duration in the manure-laden alleys.

In our survey study of 13 AMS herd (Chapter 3), we found that greater daily lying durations were associated with greater frequency of feed push-up and increased space at the feed bunk. Additionally, there was an association between cows of further DIM and longer lying durations. Contrary to the results of our first study, frequency of fresh feed delivery was not associated with longer lying durations. Similar to the hypothesis in our first study, it is possible that AMS cows feed more efficiently when feed is made more available to them, either through increased space at the feed bunk or increased feed push-up. Similarly to that reported in Chapter 2, post-milking standing duration was not affected by frequency of feed delivery in the AMS herds. It was found that cows of higher parity stood longer post-milking than cows of lower parity.

In Chapter 3 we found an association between farms that allowed more space at the feed bunk per cow and greater milk yield. There was also an association between fewer cows per robot and higher milking frequency. Further, cows of lower parities were found to have greater milking frequencies than cows of higher parities. We also found an association between cows of higher parities and greater milk yield. Finally, cows of lower DIM were associated with greater milking frequency and milk yield.

4.2 Future research

Several questions were raised from the results of our findings in the studies outlined in Chapters 2 and 3. We encourage further research on documenting the feeding
activity and social interaction of AMS cows when provided feed more frequently at the bunk. Because we did not track where cows were, and what they were doing while standing, it would be beneficial to understand, at increased frequencies of feed delivery and feed push-up, what behaviors cows are partaking in while standing. Further, we hypothesized that certain management factors were resulting in cows being more efficient feeders and performing less inactive standing, contributing to greater lying duration, but further research is needed to validate this hypothesis. It was interesting to find that post-milking standing behavior was similar to tie-stall housed cows and that cows of higher parity stood for longer periods of time after milking than younger cows. Again, this could be investigated through visual assessment of determining what cows are doing while standing, especially post milking. Finally, in terms of robot attendance, it is still undetermined, to our knowledge, why cows of lesser parity frequent the robot more so than cows of greater parity.

4.3 Implications

There are several ways in which our findings are beneficial to the AMS dairy industry. One of the major findings that could be most beneficial to producers was the association between making feed more available to cows, either through greater frequency of feed delivery or push-up, as well as through greater feed bunk space, and greater lying durations. From our results we can infer that feed bunk management does have an impact on the behavior of cows milked in AMS. With an association between greater space at the feed bunk and greater milk yield, there is an indication that cows probably do need just as much space per cow (at least 0.6 m/cow) at the feed bunk as conventional dairy systems and that reducing this space could result in a change in milk
production. Additionally, greater milking frequency in AMS may be achieved by having fewer cows per AMS unit. This, combined with our finding of a tendency of decreased milking frequency when cows had higher lameness scores, indicates that availability of the robot and the cows’ ability to walk to the robot have an impact on milking frequency. We found that cows with higher lameness scores had poorer hygiene and fewer visits to the robot. This indicates that lame cows are compromised in more ways than one on AMS dairies and that they may be at greater risk of acquiring an intramammary infection. Thus, on commercial AMS dairies, it is imperative that producers are aware of lameness and making an effort to reduce incidences of lameness in their herds. Additionally, in these systems, improved feed bunk management has the ability to improve both daily lying durations and milk yield.


