NATIONAL AGRICULTURAL AND FOOD CENTRE
RESEARCH INSTITUTE FOR ANIMAL PRODUCTION NITRA

Slovak J. Anim. Sci., 57, 2024 (2): 40–54
ISSN 1337-9984, E-ISSN 1338-0095
SciCell

Review

COW TRAFFIC DESIGNS IN BARNS WITH AUTOMATIC MILKING SYSTEMS: ADVANTAGES, DISADVANTAGES AND DIFFERENCES

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ABSTRACT

This study describes the most common traffic systems in barns for lactating dairy cows milked in automatic milking systems (AMS). It outlines seven cow traffic designs, each featuring a basic floor plan, taking into account one robot or AMS per barn and considering a maximum system capacity (>60 cows/AMS). The study describes the advantages and disadvantages of free, milk-first and feed-first traffic and the differences between forced and guided cow traffic designs. Some research data are also shown to emphasize the theoretical concepts included in this document. The main difference is that free cow traffic tends to milk a lesser number of cows than milk-first and feed-first cow traffic designs but warrants more freedom for the cows. However, free cow traffic design increases the number of refusals (cows visiting the AMS without milking permission), leading to system inefficiency. Guided traffic designs emerge as the most efficient, milking more cows throughout the day while reducing the need to fetch cows and overall labour. When operating at full cow capacity, guided cow traffic designs are recommended.

Key words: feed-first; forced cow traffic design; guided cow traffic design; milk-first; robots in agriculture

INTRODUCTION

The adoption of automatic milking systems (AMS) is becoming a global reality. Farmers opt to acquire an AMS based on their perception that it will reduce labour requirements and improve their quality of life (Jacobs and Siegford, 2012; Salfer *et al*., 2018; Tse *et al*., 2018a; 2018b). Another important factor is the scarcity and lack of skilled labour in some regions around the world (Douphrate *et al*., 2013; Hansen, 2015). Secondary motivating factors for adopting AMS include an increase in milking frequency, milk yield and improved health of the cows (Tse *et al*., 2017; Salfer *et al*., 2018).

In most situations, financial costs to acquire an AMS are large (Salfer *et al*., 2017; Unal *et al*., 2017). In larger farms, the cost of adoption of AMS are notably higher and may not compensate for the reduction of labour because of having more cows to be fetched (Pitkaranta *et al*., 2019). Given the costs involved, AMS should be operated in its maximum capacity and efficiency to counterbalance those costs (Unal *et al*., 2017; Pitkaranta *et al*., 2019).

An AMS has a milking capacity to perform about 8 milkings/hour (Ketelaar de Lauwere *et al*., 2000). Given the AMS availability of 22 hours for milking and a milking frequency ranging from 2.5 to 2.8 per cow, the system's capacity can reach approximately 60 to 70 cows (Bach and Cabrera, 2017). However, most descriptive research on AMS usage in commercial dairy farms suggests that farmers often do not fully explore or utilize the maximum capacity of these systems. Descriptive data indicate farms having about 50 to 60 cows/AMS in the United States (Tremblay *et al*., 2016, n = 529 farms; Salfer *et al*., 2018, n = 54 farms; Siewert *et al*., 2019, n = 40 farms), 49 to 55 cows/AMS in Canada (Westin *et al*., 2016, n = 36 farms; Matson *et al*., 2021, n = 197 farms), about 55 cows/AMS

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Received: February 28, 2024
Accepted: May 21, 2024

https://doi.org/10.36547/sjas.887

in Netherlands and Denmark (Markey, 2013, n = 165 farms; Van den Borne *et al*., 2022, n = 87 farms), and about 50 cows/AMS in Latvia (Gaworski *et al*., 2016, n = 4 farms). Descriptive data from Germany (about 65 cows/AMS) (Bausewein *et al*., 2022, n = 114 farms), Estonia (about 60 cows/AMS, n = 11 farms) and Poland (about 65 cows/AMS, n = 2 farms) (Gaworski *et al*., 2016) are inside the range mentioned above but few farms were evaluated in the last two countries (the same for Latvia).

Farms with 60 to 120 cows milked twice a day are the most benefited from adopting an AMS (Rotz *et al*., 2003; Pitkaranta *et al*., 2019). Generally, it results in one or two AMS per farm and per barn (Salfer *et al*., 2018; Matson *et al*., 2021). Designing a barn with more than one AMS is a challenge. Barns with one or two AMS should be preferred, whereas two AMS in a barn is only an advantage when the other is in manutention (Siewert *et al*., 2019). Until the 2000s, dairy barns were adapted to receive AMS (Bewley *et al*., 2017). Currently, most dairy barns are designed including AMS within their projects (Siewert *et al*., 2019).

The design of the barn with AMS is a determinant factor affecting the success and efficiency of the system together with the cow traffic design (CowTD; Pitkaranta *et al*., 2019; Solano *et al*., 2022). Cow traffic design refers to how cows can move inside the barn areas. Free cow traffic design (FreeTD) was the first one to be developed. It appeared together with the AMS in the 90's and is the most common CowTD (% of FreeTD: 93 %, Tremblay *et al*., 2016; 74 %, Salfer *et al*., 2018; 78 %, Siewert *et al*., 2019; 90 %, Matson *et al*., 2021). In FreeTD, cows can access any area inside the barn whenever they wish.

Around the 2000s, alternative CowTD like "semi--forced," "forced" and "guided" began to emerge as alternatives to the predominant FreeTD. They are used to improve milking frequency, reduce need to fetch cows and reduce visits without milking (Bach *et al*., 2009; Mangalis *et al*., 2021). Forced (ForcedTD) or guided (GuidedTD) cow traffic designs are based on two concepts: (1) cows need to access AMS before the feeding area (milk-first cow traffic design – MFTD) or (2) before the lying area (feed-first cow traffic design – FFTD). Using these two concepts as a basis, different ways of designing a barn with AMS can be found in the literature. However, the adoption of ForcedTD or GuidedTD is still discrete (% of ForcedTD/GuidedTD: 7 %; Tremblay *et al*., 2016; 26 %, Salfer *et al*., 2018; 22 %, Siewert *et al*., 2019; 10 %, Matson *et al*., 2021). Salfer *et al*. (2018) found that 18 % of the farms adopt MFTD and 8 % chose FFTD. The FFTD is a most recent proposed CowTD, and it is reflected in the data of Salfer *et al*. (2018).

Several studies compared CowTD regarding milking frequency, milk yield, cows' health, need to fetch cows, dry matter intake (DMI) and lying time, among other factors (Munksgaard *et al*., 2011; Helmreich *et al*., 2014; Tremblay *et al*., 2016; Siewert *et al*., 2019; Mangalis *et al*., 2021). While many studies lack detailed descriptions of plan barn designs with AMS (for example, Calamari *et al*., 2007; Hjalmarsson *et al*., 2014 and Mattachini *et al*., 2017), there are exceptions like Melin *et al*. (2007), Bach *et al*. (2009) and Munksgaard *et al*. (2011), who provided comprehensive detailed plan barn designs containing AMS. In addition, several studies do not explore the total capacity of the AMS using few cows in their research (Bach *et al*., 2009, used about 43 cows/AMS; Munksgaard *et al*., 2011, used 35 cows/AMS; Mattachini *et al*., 2019; used 48 cows/AMS). These studies involved fewer cows compared to the commercial dairy farms mentioned earlier and operating far below the capacity of the AMS (60 to 70 cows/AMS).

Overall, the current literature on CowTD lacks comprehensive details about how they work and how to manage them in practice using maximum AMS capacity. A more detailed description of simple barn designs for different CowTD is needed. Also, the characteristics, advantages and disadvantages of each cow traffic need elucidation to explore the maximum efficiency and capacity of AMS. Thus, this review intends to describe the most common CowTD in barns for lactating dairy cows milked in AMS. Simplified designs of FreeTD, MFTD and FFTD (and its versions of ForcedTD and GuidedTD) are provided considering designs of one AMS per barn. These designs can be applied to both composts, free-stall or other barns type. The characteristics, peculiarities, advantages and disadvantages of each one are discussed based on several research data to emphasize the theoretical concepts mentioned here.

COW TRAFFIC DESIGNS IN BARNS WITH AUTOMATIC MILKING SYSTEMS

Generally, a CowTD is designed into a barn project that includes an AMS. As earlier mentioned, CowTD refers to how cows can move inside the barn areas. The main objective is to make available the access to all areas inside the barn, i.e. feeding area, waiting area, lying area (whether in compost barn or free-stall; the most common barn types with AMS) and AMS for the cows. This is planned to occur in some way to warrant that cows will be milked along with the day. None or some kind of restriction can be used to warrant reaching the desired milking frequency. Nowadays, main CowTD used worldwide are based on FreeTD, MFTD or FFTD concepts. Also, ForcedTD or GuidedTD can be used in MFTD and FFTD. Literature sometimes fails to provide detailed descriptions and differences of ForcedTD and GuidedTD, sometimes treating them as synonyms (Tremblay *et al*., 2016; Rodenburg, 2017). This can be a problem when we compare different CowTD. Sometimes, ForcedTD and GuidedTD are grouped to be compared to FreeTD (Tremblay *et al*., 2016) and it can affect research findings. Rodenburg (2017) states that the main difference between ForcedTD and GuidedTD is the use of a selection gate in GuidedTD instead of only one-way gates.

Free cow traffic design

Traditional free cow traffic design

Traditional FreeTD is the most common CowTD used in dairy barns containing AMS. It was the first one to be used with the emergence of AMS. Cows in FreeTD can access any area inside the barn (feeding area, lying area, waiting area and the AMS) anytime they wish (Figure 1A). The waiting area is just an opened

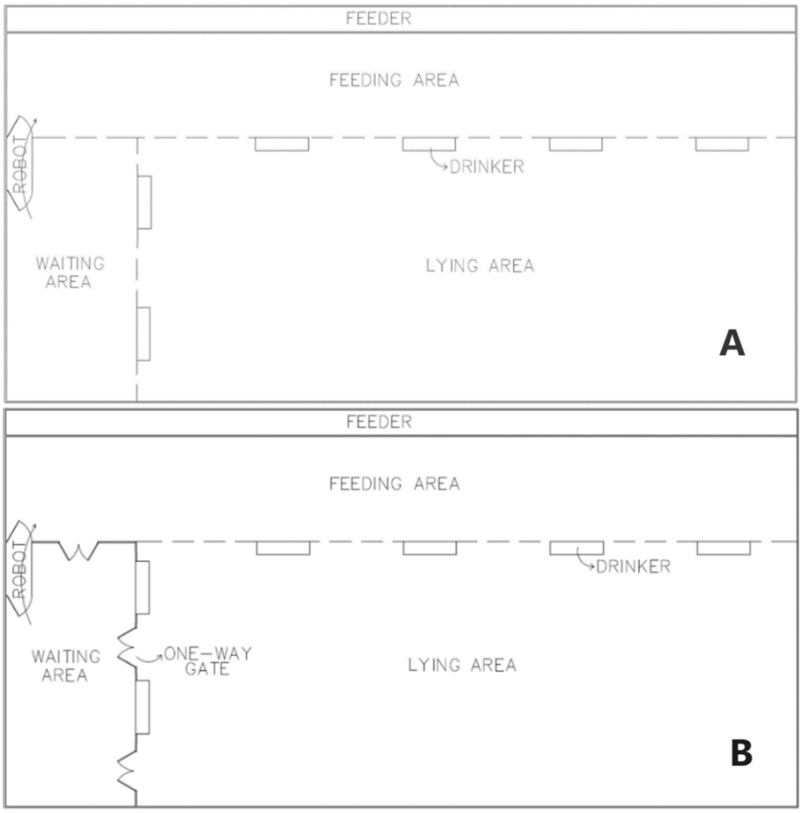

Figure 1. Free cow traffic designs in barns with automatic milking systems (AMS) considering one AMS per barn. The designs are suitable for both compost bedded pack and free-stall housing. The AMS is represented by "Robot" in the figures. A) Traditional free cow traffic design (FreeTD): cows can access any area inside the barn indicated by dashed lines (feeding area, lying area, waiting area, and the AMS). Here waiting area is just a concreted area in front of the AMS. Cows that visit the robot without permission for milking are immediately refused by the robot. B) Free cow traffic design with a waiting area (FreeTDWA): cows can enter the waiting area through a one-way gate, but they can only exit by passing through the AMS; dashed line indicates cows can access feeding and lying areas when they wish. Cows that visit the robot without permission for milking are immediately refused by it.

concreted area in front of the AMS. Visits on AMS are warranted providing adequate concentrate in AMS (Jacobs and Siegford 2012; Bach and Cabrera, 2017). This is the main motivation for cows visiting the AMS in FreeTD. Therefore, adequate management of feed provision in AMS is crucial (Pitkaranta *et al*., 2019). When a cow without milking permission access the AMS, generally, the system is programmed to refuse it.

Free cow traffic design with a closed waiting area

Free cow traffic design with a closed waiting area (FreeTDWA) has the same general working concept of the FreeTD, however, a closed waiting area is included. Cows, wishing to access AMS, must enter the waiting area from one-way gates (Figure 1B). The unique way to exit the waiting area is through the AMS. Cows without milk permission that access the AMS are refused by the system. The FreeTDWA was planned as a try to reduce the time spent directing fetch cows to the AMS (Markey, 2013; Unal and Kuraloglu, 2015). Therefore, fetch cows can be only directed to the waiting area. Once in the waiting area, they must access the AMS.

Forced and guided traffic designs

Forced milk-first cow traffic design

A ForcedTD restricts cows from accessing one of the areas of the barn. Cows only can access the restricted area by accessing the waiting area and AMS. In forced milk-first cow traffic design (ForcedMFTD), all cows in

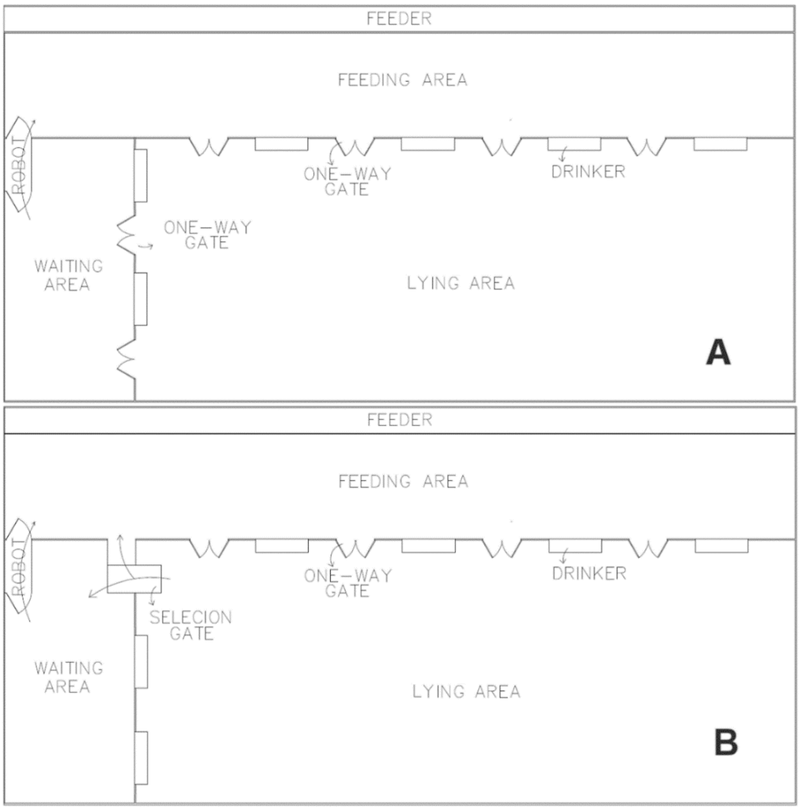

Figure 2. Milk-first cow traffic designs in barns with automatic milking systems (AMS) considering one AMS per barn. The designs are suitable for both compost bedded pack and free-stall housing. The AMS is represented by "Robot" in the figures. A) Forced milk-first cow traffic (ForcedMFTD): all cows must enter the waiting area through one-way gates and pass through the AMS to access the feeding area. Cows that have no permission for milking are immediately refused by the robot. In feeding area, when they decide to lay down, they can access the lying area through one-way gates. B) Guided milk-first cow traffic (GuidedMFTD): cows are guided by a selection gate to the feeding area if they have no permission for milking or to the waiting area if they have permission for milking. The selection gate is the unique way to access the feeding area and, when cows decide to lay down, they can access the lying area via one-way gates.

lying area must access the waiting area via one-way gates and pass through the AMS to get access to the feeding area (Figure 2A). Only one cow at a time can access the feeding area (via AMS). Once in the feeding area, cows can return to the lying area when they wish via one-way gates (Figure 2A). Cows without milk permission that access the AMS are refused by the system and directed to feeding area immediately.

Guided milk-first cow traffic design

A GuidedTD uses a selection criterion to direct the cow to a specific area inside the barn. In a guided milk-first cow traffic design (GuidedMFTD), the traffic follows the ForcedMFTD. However, cows access the waiting area or feeding area via a selection gate instead of one way-gates (Figure 2B). Cows with milking permission are directed to the waiting area and must access the AMS for milking before access feeding area (Figure 2B). Cows without milking permission are directed to the feeding area instead (Figure 2B). Once in the feeding area, cows can return to the lying area whenever they wish via one-way gates (Figure 2B). Only one cow at a time can access the feeding area (via selection gate or AMS).

Forced feed-first cow traffic design

The forced feed-first cow traffic design (ForcedFFTD) is similar to the ForcedMFTD but with the traffic in the opposite direction. Cows in lying area can access the feeding area when they wish via one-way gates (Figure 3A). Several cows can quickly access the feeding area in ForcedFFTD because we have several one-way gates (Figure 3A). When cows wish to rest, they must access the waiting area via one-way gates and access the AMS (Figure 3A). If they had milking permission they are milked, otherwise they are refused to the lying area immediately.

Guided feed-first cow traffic design

A guided feed-first cow traffic design (GuidedFFTD) can be designed in two ways, where cows exiting AMS to the lying area (GuidedFFTDLA) (Figure 3B) or to the feeding area (GuidedFFTDFA) (Figure 3C). The flow is exactly the opposite of the GuidedMFTD. Cows in lying area can access the feeding area when they wish via one-way gates (Figure 3B and 3C). In both GuidedFFTDs, several cows can quickly access the feeding area because we have several one-way gates. When cows wish to rest, they need to access a selection gate that directs cows to the waiting area (those with milking permission) or the lying area (those without milking permission) (Figure 3B and 3C). In GuidedFFTDLA, cows in the waiting area access the AMS for milking and, after that they are directed to the lying area (Figure 3B). In GuidedFFTDFA, cows in the waiting area access the AMS for milking and, after that they are directed to the feeding area, needing to access again the selection gate to be directed to the lying area (Figure 3C). Manufacturers mention that GuidedFFTDFA is preferred and should be used to prevent cows from lying down while the sphincter is open, preventing contamination and the occurrence of mastitis.

DIFFERENCES, ADVANTAGES AND DISADVANTAGES OF COW TRAFFIC DESIGNS

Regarding to cows

Milk yield per cow

CowTD exert slight effects on the daily mean milk yield of cows. Main difference should be attributed to milking frequency, where a greater milking frequency tends to correlate with a higher daily mean milk yield per cow milked in AMS (Tremblay *et al*., 2016; Vijayakumar *et al*., 2017; Van den Borne *et al*., 2022). Based on it, CowTD, that improve milking frequency, has potential to increased daily mean milk yield per cow. When the system is running at full capacity, GuidedTD tends to have an advantage over the others.

Data comparing the daily mean milk yield per cow among the CowTD indicate slight and variable differences (Markey, 2013; Gaworski *et al*., 2016; Siewert *et al*., 2019). However, the differences are primarily influenced by factors like genetics, diets and the specific moment of the herd (age and days in milk of the cows) rather than solely by CowTD.

Primiparous seems to have milking frequency improved in FreeTD and, consequently, daily mean milk yield per cow (Siewert *et al*., 2019). Also, some studies found that the increase in the provision of concentrate in AMS may increase the daily mean milk yield (Henriksen *et al*., 2018, Menajovsky *et al*., 2018), while others have not observed an effect (Bach *et al*., 2007; Schwanke *et al*., 2022).

Milking frequency and visits on AMS

Milking frequency is highly correlated to milk yield, especially in AMS. The ForcedTD and GuidedTD

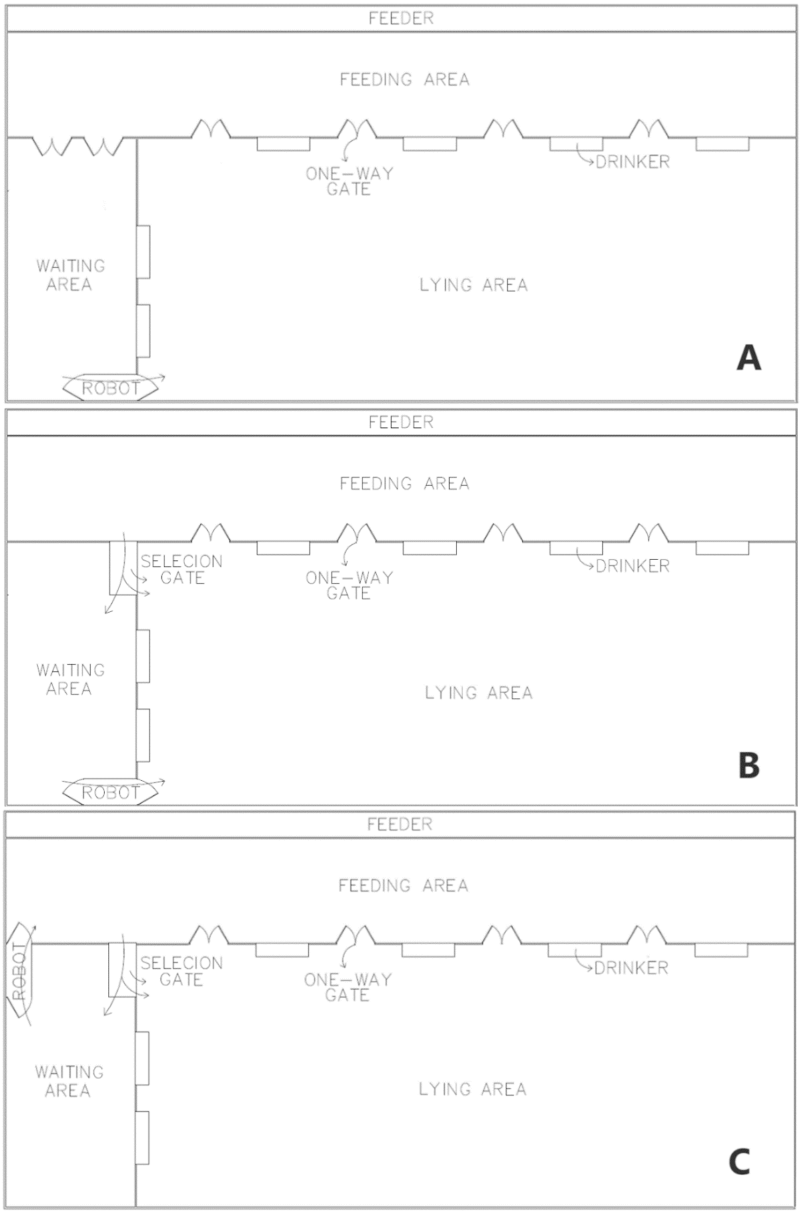

Figure 3. Feed-first cow traffic designs in barns with automatic milking systems (AMS) considering one AMS per barn. The designs are suitable for both compost bedded pack and free-stall housing. The AMS is represented by "Robot" in the figures. A) Forced feed-first cow traffic (ForcedFFTD): all cows can access the feeding area through one-way gates but must enter the waiting area and pass through AMS to return to the lying area. Cows that have no permission for milking are immediately refused by the robot. B) Guided feed-first cow traffic with cows being directed to the lying area once they have been milked (GuidedFFTDLA): all cows can access the feeding area through one-way gates, and when they decide to return to the lying area or access the AMS, they are guided by a selection gate to the waiting area if they have permission for milking or to the lying area if they have no permission for milking. Cows in the waiting area need to access the AMS and are then directed to the lying area once they have been milked. C) Guided feed-first cow traffic with cows being directed to the feeding area once they have been milked (GuidedFFTDFA): all cows can access the feeding area through one-way gates, and when they decide to return to the lying area or access the AMS, they are guided by a selection gate to the waiting area if they have permission for milking or to the lying area if they have no permission for milking. Cows in the waiting area need to pass through the AMS and are then directed to the feeding area once they have been milked. So, they need to access the selection gate again to be guided to the lying area."

have high potential in maximizing milking frequency per cow and per AMS/day by directing cows efficiently to the AMS. Several studies have indicated that ForcedTD and GuidedTD reach a greater milking frequency compared to FreeTD (Harms *et al*., 2002; Thune *et al*., 2002; Hermans *et al*., 2003; Bach *et al*., 2009; Castro *et al*., 2012; Bach and Cabrera, 2017; Unal *et al*., 2017). However, if an AMS reaches full capacity (>60 cows/AMS), GuidedTD has a quick advantage in maximizing milking frequency. Under those circumstances, both FreeTD and ForcedTD approaches can lead to increased visits to the AMS without milking (refusals) (Harms *et al*., 2002; Thune *et al*., 2002; Hermans *et al*., 2003; Bach *et al*., 2009; Munksgaard *et al*., 2011). In FreeTD and FreeTDWA, cows have the freedom to access the AMS whenever they choose, while in ForcedTD cows are forced to visit the AMS to reach the feeding or lying area. In both situations, cows without permission to be milked will spend box time, thereby reducing the AMS availability for milking throughout the day. The GuidedTD reduces AMS workload by minimizing repeated visits from cows that have already been milked (Mangalis *et al*., 2021).

The AMS manufacturers and the dairy industry often suggest that increasing concentrate provision in AMS, particularly in FreeTDs, could lead to increased milking visits (Johnson *et al*., 2022). This argument is often used by Lely manufacturer that basically designs and recommends FreeTD, but others also share this opinion (DeLaval, GEA Farm Technologies, and Lemmer-Fullwood). However, the current literature does not support it. Several studies suggest that the amount of concentrate provided in AMS does not correlate with the milking frequency (Halachmi *et al*., 2005; Bach *et al*., 2007; Hare *et al*., 2018; Menajovsky *et al*., 2018; Paddick *et al*., 2019; Schwanke *et al*., 2022). Whether small or large amounts are provided, they lead to similar milking frequencies. Hence, providing large amounts of concentrate in a FreeTD may not rise the milking frequency as thought (Bach *et al*., 2007).

However, increasing the frequency of feed delivery in the feeding area leads to increased cow activity, with more cows eating and visiting the AMS for milking (Rodenburg, 2002; Oberschätzl-Kopp *et al*., 2016; Mattachini *et al*., 2017; Matson *et al*., 2021). Similarly, the frequency of feed push-up results also in increased cow activity and milking frequency but with a lesser intensity (DeVries and Von Keyserlingk, 2009; Oberschätzl-Kopp *et al*., 2016; Matson *et al*., 2021). These practices have a more pronounced effect in ForcedTD and GuidedTD on increasing the milking frequency compared to FreeTDs, because cows are required to enter or are guided to the waiting area at some moment (Rodenburg, 2002).

The milking frequency is also influenced by the milking permission settings configured for the cows. Generally, primiparous, fresh cows and high-yielding ones are allowed to milk in short intervals (Helmreich *et al*., 2014). Schwanke *et al*. (2022) set the milking permission for cows in FreeTD to allow milking within a 4-hour window after the last milking. This approach led to an increased milking frequency (more than 3 milkings/cow), however, the study was limited to a sample size of only 15 cows that does not represent the conditions found in typical dairy farms employing AMS. A short milking interval can lead to system inefficiencies by harvesting only small amounts of milk per hour, thus keeping the AMS occupied without maximizing milk yield and time.

Fetch cows

The profitability of AMS is achieved by maximizing milking frequency and reducing the necessity to fetch cows (Bach and Cabrera, 2017). Cows that require guidance to the AMS for milking are called fetch cows. Fetch cows include early and late lactation cows, those that are lame and sick, as well as cows that require human interaction to visit the AMS due to insufficient training (Pitkaranta *et al*., 2019). Occasionally, cows experiencing demotivation may need to be fetched due to factors like barn design, the number of cows in the barn and waiting area, inadequately planned diets and limitations in pellet allowances within the AMS (Pitkaranta *et al*., 2019). Designs promoting FreeTDs have substantial disadvantages in fetching cows when compared to ForcedTD and GuidedTD.

Some research indicates that in FreeTD more cows need to be fetched. Rodenburg and House (2007) observed that in FreeTD, 16% of cows were fetched, whereas only 8 % were fetched in ForcedTD and/or GuidedTD. Bach *et al*. (2009) noted a fivefold increase in involuntary milking in FreeTD, emphasizing the reduced need to fetch cows with ForcedTD and/or GuidedTD. Salfer *et al*. (2018) and Siewert *et al*. (2019) found 8 % of fetched cows in FreeTD compared to 5 % in ForcedTD or GuidedTD. However, Salfer *et al*. (2018) collected data based on farmers' responses and those using FreeTD report fetching fewer cows, whereas

Siewert *et al*. (2019) did not mention about how data about fetch cows were collected. Therefore, those percentages may be greater than 8 % of fetched cows in FreeTD.

Once again, the manufacturers and dairy industry suggest that increasing the amount of feed in AMS will decrease the need for fetch cows considering it as a strategy to increase voluntary visits especially in FreeTD. However, the scientific literature does not support that practice. Increasing the amount of concentrate in AMS does not reduce the need to fetch cows (Bach *et al*., 2007; Schwanke *et al*., 2022). Provision of more concentrate in AMS will just increase the milking frequency in cows that do not need to be fetched (Bach *et al*., 2007).

Farmers will need to fetch cows in all CowTD. Typically, in the morning, there is a higher occurrence of cows to be fetched, as they visit the AMS less frequently during the night. It results in a higher number of milkings occurring in the morning (Bach *et al*., 2009). A few hours after delivering feed in the feeding area (until about 2 h after that), it is expected that the number of cows in the waiting area increases in most of the CowTD. However, this may not be true for MFTD, especially for GuidedMFTD. At the first feed delivery moment of the day (assuming it is provided at 6 AM, for example), cows tend to be more agitated as they expect feeding. When feed is provided, in FreeTDs and FFTDs, either no cows or fewer cows will enter the waiting area for milking, whereas the opposite case is observed for MFTDs. It might be perceived as an advantage for the MFTDs, since in other designs there is a necessity to fetch some cows at that moment. However, this represents a true disadvantage for MFTDs, especially the GuidedMFTD compared to GuidedFFTD. In GuidedMFTD, cows access the feeding area exclusively through the selection gate being their only pathway to access it. It can cause some competition and potential traffic congestion at the selection gate, differently from FreeTDs and FFTDs. Furthermore, the waiting area is designed to accommodate a restricted number of cows. If this capacity is reached, other cows with milking permission approaching the selection gate are directed towards the feeding area. In the feeding area, cows can freely return to the lying area as they wish, which might result in the need for fetching later, if they do not re-enter the selection gate to access the waiting area. In GuidedFFTD, during the first feed delivery of the day, all cows can access the feeding area via one-way gates. Hence, there is no competition or congestion observed at the selection gate during this period. In this scenario, the waiting area will have no cows or only a few, allowing for the possibility of fetching some cows to be milked in the meantime. As the morning progresses, cows in the feeding area need to access the selection gate to return to the lying area and those with milking permission are being directed towards waiting area and AMS. The feeding area acts as an additional waiting area in GuidedFFTD, significantly reducing the necessity to fetch cows. In FreeTD, all cows can access the feeding area during the first feed delivery time of the day. However, there is no assurance that they will access the AMS, potentially resulting in more cows needed to be fetched.

Interactions among cows and social ranking

The interactions among cows play a crucial role in the proper functioning of AMS. Cows of higher social rank often involve older and larger individuals (Melin *et al*., 2006; Halachmi, 2009; Solano *et al*., 2022). In ForcedTDs and GuidedTDs, cows' interactions within the waiting area are intensified. In such scenarios, cows with lower social rankings are disproportionately affected as they experience longer wait times to access the AMS without the option to exit the waiting area (Melin *et al*., 2006; Halachmi, 2009; Pitkaranta *et al*., 2019). The impact of social ranking on lower-ranked cows intensifies as the barn's population increases (Tremblay *et al*., 2016). However, lower-ranked cows might wait for moments of reduced competition to access the waiting area and AMS (Helmreich *et al*., 2014). Despite the advantage of a reduced social hierarchy in FreeTDs, some cows may experience demotivation to visit the AMS, particularly in situations where there are more than 60 cows per AMS. In such scenarios, high-ranked cows might visit the AMS so often that lower-ranked cows (especially primiparous) may eventually need to be fetched at certain times of the day.

In ForcedTDs and GuidedTDs, although the interaction and dominance of high-ranked over lower-ranked cows is intensified, lower-ranked cows will eventually need to access the AMS to exit the waiting area. The urge for feed or rest will motivate those lower-ranked cows to access the AMS. The GuidedTDs creates an opportunity for lower-ranked cows to access the AMS by directing cows without milking permission to areas other than the waiting area and may reduce scenarios of dominance.

Feeding and resting behaviour

The DMI in different CowTD has been previously assessed highlighting its significance as a crucial indicator of health and performance in dairy cattle (Bareille *et al*., 2003). The CowTD significantly influences DMI behaviour. In FreeTDs, cows have more frequent but smaller meals and spend less time eating in the feeding area, whereas in ForcedTDs and GuidedTDs cows have fewer but larger meals and spend more time eating in the feeding area (Calamari *et al*., 2007; Bach *et al*., 2009; Munksgaard *et al*., 2011). This difference is particularly pronounced in primiparous cows (Calamari *et al*., 2007). However, total daily DMI is not affected by CowTD (Melin *et al*., 2007; Bach *et al*., 2009).

When there is an increase in concentrate provided through AMS, it typically leads to a reduction in DMI within the feeding area (forage intake) (Bach *et al*., 2007; Hare *et al*., 2018; Menajovsky *et al*., 2018; Schwanke *et al*., 2022). CowTD that permits cows to consume concentrate before accessing the feeding area can induce satiety, consequently leading to lower overall daily DMI (Bach *et al*., 2007). Concerns exist about cows consuming high amounts of concentrate in AMS, particularly before forage, which could potentially lead to subacute ruminal acidosis. However, research suggests that in well-planned diets this practice does not affect ruminal pH negatively (Menajovsky *et al*., 2018; Paddick *et al*., 2019).

Generally, FFTDs might potentially offer advantages by increasing daily DMI and avoiding abrupt decreases in ruminal pH, given that cows consume forage first. An additional advantage of FFTDs to MFTDs is that cows have multiple access points to the feeding area through several one-way gates. If cows cannot eat while others are feeding, they do not come back to eat more later (Pitkaranta *et al*., 2019). Obviously, in FreeTDs, cows have the freedom to access the feeding area whenever they choose. However, they might have already consumed concentrate before forage, feeling partially satiated and eating less in feeding area.

CowTD also affects the resting behaviour of the cows. Similar to feeding behaviour, cows in FreeTDs have more frequent but shorter resting events, while cows in ForcedTDs and GuidedTDs have fewer but longer resting events (Hermans *et al*., 2003; Calamari *et al*., 2007; Lexer *et al*., 2009; Munksgaard *et al*., 2011; Mattachinni *et al*., 2019; Schwanke *et al*., 2022). In the end of the day, the total time spent resting did not differ significantly among different CowTD, typically ranging from 11 to 12 hours (Westin *et al*., 2016; Mattachinni *et al*., 2019). ForcedTDs has a disadvantage related to resting events compared to the others CowTD. Once all cows must initially pass through the waiting area and AMS before reaching the feeding or lying area, they might end up standing for extended periods. Also, this scenario might suggest a necessity for larger waiting areas in ForcedTDs. However, when a CowTD is well-planned, cows tend to maintain a consistent behavioural pattern, consuming less and resting more at night and adjusting their activity timings throughout the day (DeVries *et al*., 2011; Munksgaard *et al*., 2011).

Foot and claw disorders

Foot and claw disorders can impact milk yield in AMS in two ways: they can reduce yield by decreasing DMI due to the foot and claw problem, and lame cows tend to visit the AMS less frequently, resulting in reduced milkings (Urbonavicius *et al*., 2020; Van den Borne *et al*., 2022). Managing foot and claw disorders is crucial in AMS because they significantly impact the necessity to fetch cows (Pitkaranta *et al*., 2019).

Studies suggest that cows standing for extended periods are more susceptible to developing foot and claw disorders (Blowey, 2005; Barker *et al*., 2008). Based on it, there is a suggestion in favour of using FreeTDs vs. ForcedTDs and GuidedTDs, implying that cows would spend less time standing and could rest when they wish. Therefore, FreeTDs potentially would reduce the likelihood of foot and claw disorders. However, as previously highlighted, the daily resting time is not impacted by the specific CowTD utilized. Depending on the CowTD, cows adapt their resting behaviour to achieve about 12 hours of daily resting time. In addition, hock and knee lesions do not seem to influence any factors associated with resting behaviour in cows in AMS (Westin *et al*., 2016). Like mastitis, foot and claw disorders are multifactorial (Alvergnas *et al*., 2019; Moreira *et al*., 2019), and we do not have any scientific evidence to attribute CowTD as one of the main causal factors.

Regarding to farmers

Compost vs. free-stall barns

There is a lack of comparative analysis in the literature regarding the most suitable CowTD for various types of rearing barns. There are no studies evaluating the interaction between barn type and

CowTD. Most AMS systems are installed in free-stall barns, while other barn types are less commonly used with AMS (Salfer *et al*., 2018; Siewert *et al*., 2019). In a free-stall barn, cows may show a preference for specific individual beds or pens rather than others, which might be associated with their hierarchy in the herd (Friend and Polan, 1974; Cecchin *et al*., 2015). A cow using a bed pen situated farther from the AMS might be less motivated to visit the AMS. This demotivation might be more pronounced in ForcedTDs and GuidedTDs. Another concern in free-stall barns is the competition for bed pens when new cows are introduced to the barn. This may lead to some cows being unable to find a bed pen and deciding to lie on the runway instead.

In a compost barn, cows have the flexibility to utilize any part of the bedding area, rather than having designated individual areas as in a free-stall barn. It seems to be a more favourable barn type for primiparous and new cows, allowing them to avoid competition scenarios often seen with multiparous and dominant cows. In a free-stall barn, cows often stand on concrete flooring, while in a compost barn, they stand in a softer bedding material, which results in improved foot and claw health (Burgstaller *et al*., 2016; Kogima *et al*., 2022). This aligns with the earlier discussions, where fewer foot and claw disorders lead to a reduced number of fetch cows. Therefore, the implementation of ForcedTDs and GuidedTDs may be more effective in compost barns. However, the implantation of a compost barn is significantly dependent on the farm relief for adequate natural environmental ventilation. The relationship between barn type and CowTD remains a topic that requires further investigation and research.

Workload and labour

The adoption of AMS is primarily driven by the aim to reduce labour and enhance the quality of life for farmers (Mathijs *et al*., 2004; Heikkila *et al*., 2010; Tse *et al*., 2018a; Salfer *et al*., 2018). Farmers have reported that their health and profitability improved with the implementation of AMS (Tse *et al*., 2017; 2018a; Salfer *et al*., 2017). However, reducing labour is not always feasible due to the number of cows that need to be fetched and directed to the AMS (Jacobs and Siegford, 2012). In this context, ForcedTDs and GuidedTDs are considered the most promising for reduction of workload and labour in AMS. As mentioned earlier, the FreeTDs leads to more fetch cows. As a result, people spend more time directing cows to milking in FreeTDs compared to ForcedTDs and GuidedTDs. Unal *et al*. (2017) indicated that FreeTDs demands double time spent of labour compared to GuidedTDs (0.11 vs. 0.05 person.h^{-1}/cow.day^{-1}, respectively). Therefore, barn designs have important influence on workload and labour in AMS (Pitkaranta *et al*., 2019).

Implementation cost

As earlier mentioned, initially, dairy barns were adapted to receive AMS (Bewley *et al*., 2017) and currently, most dairy barns are designed including AMS within their projects (Siewert *et al*., 2019). Designing a barn with an AMS will likely be more cost-effective than building a barn without an AMS and later installing one, which would require structural modifications and adjustments to the existing barn. The ForcedTDs and GuidedTDs implementations tend to be more expensive than FreeTDs due to additional structural costs, such as one-way gates, retainers and ironmongery needed to guide cows in specific areas of the barn. Furthermore, GuidedTDs incurs an additional cost with the implementation of a selection gate. Indeed, the FreeTDs hold a significant advantage in terms of implementation cost compared to ForcedTDs and GuidedTDs. I might speculate that implementation cost may be one of the main reasons for the implantation of a FreeTDs, but I do not have evidence to support it. Another remained question is whether the initially higher implantation cost, especially for GuidedTDs, is financially offset later by the reduction in workload and labour.

Capacity, efficiency and milk yield per AMS

Capacity, efficiency and milk yield per AMS are related to each other within AMS systems. Having more than 60 cows per AMS would mean more milkings in a day becoming the system more efficient. When there are fewer than 60 cows per AMS, there might be increased AMS idle time, reducing efficiency and daily milk yield per AMS (Siewert *et al*., 2019). However, with a higher number of cows in the AMS, the frequency of milking/cow tends to decrease (Gaworski *et al*., 2016). Hence, it is crucial to plan an appropriate configuration for milking permissions in each specific scenario to maintain milking frequency and efficiency of the system (Schwanke *et al*., 2022).

Refusals directly contribute to AMS inefficiency, and it is observed that having a greater number of cows in the barn usually leads to fewer refusals throughout the day (King *et al*., 2017; Siewert *et al*., 2019). A high number of refusals is commonly observed in FreeTDs than in ForcedTDs and GuidedTDs, often because cows have unrestricted access to the AMS (Unal *et al*., 2017). Also, Lely manufacturers recommend maintaining more than one refusal per cow per day in FreeTDs as an incentive for cows to visit the AMS (Kozłowska *et al*., 2013; Siewert *et al*., 2019), but it makes the system less efficient. The ForcedTDs has an intermediate efficiency because, while it enhances milking frequency, it also tends to increase the number of refusals. The GuidedTDs appears to be the most efficient when the system operates at full capacity as it enhances milking frequency and reduces refusals through the use of a selection gate.

Studies indicate that ForcedTDs and GuidedTDs result in higher milk yield per day per AMS compared to the FreeTDs due to the higher milking frequency (Bach *et al*., 2009; Gaworski *et al*., 2016). In contrast, Tremblay *et al*. (2016) found that FreeTDs yielded more milk/AMS vs. ForcedTDs/GuidedTDs. However, their data may be biased, as 93 % of the information comes from FreeTDs and only Lely AMS were evaluated. Lely manufacturers argue in favour of FreeTDs, creating a contradiction when considering that Lely AMS were also implemented in ForcedTDs/GuidedTDs. Furthermore, there is a lack of clarification regarding the design of ForcedTDs or GuidedTDs utilizing Lely AMS in the study. With 93 % of the data sourced from FreeTDs, it is probable that a substantial proportion of herds with high milk yield were included in this group, consequently favouring FreeTDs.

FINAL CONSIDERATIONS

Any CowTD can work effectively due to an adequate nutritional planning, optimized milking permission settings and well-trained cows. However, when reaching full AMS capacity (>60 cows/AMS), some CowTDs may exhibit certain advantages and/or disadvantages. The daily mean milk yield per cow does not seem to be greatly affected by CowTD, but it is influenced by an increase in milking frequency, which may be observed in ForcedTDs and GuidedTDs. So, milking frequency notably increases in ForcedTDs and GuidedTDS. In FreeTDs, interactions and dominance effects among cows are minimized. Also, freedom for feeding and resting is increased in FreeTDs. However, no significant differences were found in total daily DMI and resting time among different CowTDs. For foot and claw disorders, ForcedTDs appear to have a slight disadvantage compared to other CowTDs, because cows spend more time standing in waiting area until access AMS. Labour is notably reduced in ForcedTDs and GuidedTDs, particularly in the need to fetch cows, with a slight advantage for GuidedFFTDs. Capacity, efficiency and milk yield per AMS are also elevated for GuidedTDs. The implementation costs are lower for FreeTDs, which might be a significant reason behind its adoption. Choosing between FreeTDs or GuidedTDs could be preferable, given that GuidedTDs are an improvement over ForcedTDs. In the future, with more farms adopting GuidedTDs we will have a larger dataset for adequate comparisons among CowTDs.

ACKNOWLEDGEMENTS

The author thanks to the High Uruguay and Missions Regional Integrated University, which supported that research.

FUNDING

Not applicable.

AUTHOR CONTRIBUTION

All roles were performed by the author.

CONFLICT OF INTEREST

No potential conflict of interest was reported by the author.

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REFERENCES

Alvergnas, M., Strabel, T., Rzewuska, K. & Sell-Kubiak, E. (2019). Claw disorders in dairy cattle: Effects on production, welfare and farm economics with possible prevention methods. *Livestock Science*, 222, 54–64. https://doi.org/10.1016/j.livsci.2019.02.011

Bach, A. & Cabrera, V. (2017). Robotic milking: Feeding strategies and economic returns. J*ournal of Dairy Science*, 100(9), 7720–7728. https://doi.org/10.3168/jds.2016-11694

Bach, A., Devant, M., Igleasias, C. & Ferrer, A. (2009). Forced traffic in automatic milking systems effectively reduces the need to get cows, but alters eating behavior and does not improve milk yield of dairy cattle. *Journal of Dairy Science*, 92(3), 1272–1280. https://doi.org/10.3168/jds.2008-1443

Bach, A., Iglesias, C., Calsamiglia, S. & Devant, M. (2007). Effect of amount of concentrate offered in automatic milking systems on milking frequency, feeding behavior, and milk production of dairy cattle consuming high amounts of corn silage. *Journal of Dairy Science*, 90(11), 5049–5055. https://doi.org/10.3168/jds.2007-0347

Bareille, N., Beaudeau, F., Billon, S., Robert, A. & Faverdin, P. (2003). Effects of health disorders on feed intake and milk production in dairy cows. *Livestock Production Science*, 83 (1), 53–62. https://doi.org/10.1016/S0301-6226(03)00040-X

Barker, Z. E., Amory, J. R., Wright, J. L., Mason, S. A., Blowey, R. W. & Green, L. E. (2008). Risk factors for increased rates of sole ulcers, white line disease, and digital dermatitis in dairy cattle from twenty-seven farms in England and Wales. *Journal of Dairy Science*, 92(5), 1971–1978. https://doi.org/10.3168/jds.2008-1590

Bausewein, M., Mansfeld, R., Doherr, M. G., Harms, J. & Sorge, U. S. (2022). Sensitivity and specificity for the detection of clinical mastitis by automatic milking systems in Bavarian dairy herds. *Animals*, 12(16), 2131. https://doi.org/10.3390/ani12162131

Bewley, J. M., Robertson, L. M. & Eckelkamp, E. A. (2017). A 100-Year Review: Lactating dairy cattle housing management. *Journal of Dairy Science*, 100(12), 10418–10431. https://doi.org/10.3168/jds.2017-13251

Blowey, R. (2005). Factors associated with lameness in dairy cattle. *In Practice*, 27(3), 154–162. https://doi.org/10.1136/inpract.27.3.154

Burgstaller, J., Raith, J., Kuchling, S., Mandl, V., Hund, A. & Kofler, J. (2016). Claw health and prevalence of lameness in cows from compost bedded and cubicle freestall dairy barns in Austria. *The Veterinary Journal*, 216, 81–86. https://doi.org/10.1016/j.tvjl.2016.07.006

Calamari, L., Petrera, F., Fava, A. & Stefanini, L. (2007). Feeding behaviour of dairy cows in forced or free cow traffic in Automatic Milking System (AMS). *Italian Journal of Animal Science*, 6(S 1), 410. https://doi.org/10.4081/ijas.2007.1s.410

Castro, A., Pereira, J. M., Amiama, C. & Bueno, J. (2012). Estimating efficiency in automatic milking systems. *Journal of Dairy Science*, 95 (2), 929–936. https://doi.org/10.3168/jds.2010-3912

Cecchin, D., Campos, A. T., Yanagi Junior, T., Pires, M. F. A., Lourençoni, D., Sousa, F. A. & Cecchin, D. 2015. Frequency of free-stall occupancy by dairy cows. *Journal of Animal Behavior and Biometeorology*, 3(4), 107–115. http://dx.doi.org/10.14269/2318-1265/jabb.v3n4p107-115

DeVries, T. J. & von Keyserlingk, M. A. G. (2009). Understanding feeding behavior to maximize the potential of dairy rations. *Proceedings Mid-South Ruminant Nutrition Conference*, April 6–7, Arlington, Texas.

DeVries, T. J., Deming, J. A., Rodenburg, J., Seguin, G., Leslie, K. E. & Barkema, H. W. (2011). Association of standing and lying behavior patterns and incidence of intramammary infection in dairy cows milked with an automatic milking system. *Journal of Dairy Science*, 94(8), 3845–3855. https://doi.org/10.3168/jds.2010-4032

Douphrate, D. I., Hagevoort, G. R., Nonnenmann, M. W., Kolstrup, C. L., Reynolds, S. J., Jakob, M. & Kinsel, M. (2013). The dairy industry: A brief description of production practices, trends, and farm characteristics around the world. *Journal of Agromedicine*, 18(3), 187–197. https://doi.org/10.1080/1059924X.2013.796901

Friend, T. H. & Polan, C. E. (1974). Social rank, feeding behavior, and free stall utilization by dairy cattle. *Journal of Dairy Science*, 57(10), 1214–1220. https://doi.org/10.3168/jds.S0022-0302(74)85040-X

Gaworski, M., Leola, A., Sada, O., Kic, P. & Priekulis, J. (2016). Effect of cow traffic system and herd size on cow performance and automatic milking systems capacity. *Agronomy Research*, 14(1), 33–40.

Halachmi, I. (2009). Simulating the hierarchical order and cow queue length in an automatic milking system. *Biosystems Engineering*, 102(4), 453–460. https://doi.org/10.1016/j.biosystemseng.2009.01.010

Halachmi, I., Ofir, S. & Miron, J. (2005). Comparing two concentrate allowances in an automatic milking system. *Animal Science*, 80(3), 339–343. https://doi.org/10.1079/ASC40480339

Hansen, B. G. (2015). Robotic milking-farmer experiences and adoption rate in Jæren, Norway. *Journal of Rural Studies*, 41, 109–117. https://doi.org/10.1016/j.jrurstud.2015.08.004

Hare, K., DeVries, T. J., Schwartkopf-Genswein, K. S. & Penner, G. B. (2018). Does the location of concentrate provision affect voluntary visits, and milk and milk component yield for cows in an automated milking system? *Canadian Journal of Animal Science*, 98(2), 399–404. https://doi.org/10.1139/cjas-2017-0123

Harms, J., Wendl, G. & Schön, H. (2002). Influence of cow traffic on milking and animal behaviour in a robotic milking system. *Proceedings of The First American Conference on Robotic Milking,* March 20–22, Toronto, Canada. https://doi.org/10.3920/9789086865253_116

Heikkilä, A. M., Vanninen, L. & Manninen, E. (2010). Economics of small-scale dairy farms having robotic milking. *Proceedings of the first North American conference on precision dairy management*, March 2–5, Toronto, Canada.

Helmreich, S., Hauser, R., Jungbluth, T., Wechsler, B. & Gygax, L. (2014). Time-budget constraints for cows with high milking frequency on farms with automatic milking systems. *Livestock Science*, 167, 315–322. https://doi.org/10.1016/j.livsci.2014.06.014

Henriksen, J. C. S., Munksgaard, L. & Weisbjerg, M. R. (2018). Short-term responses in production and behavior during periods of change in concentrate allowance for dairy cows. *Journal of Dairy Science*, 101(9), 7942–7953. https://doi.org/10.3168/jds.2018-14624

Hermans, G. G. N., Ipema, A. H., Stefanowska, J. & Metz, J. H. M. (2003). The effect of two traffic situations on the behavior and performance of cows in an automatic milking system. *Journal of Dairy Science*, 86(6), 1997–2004. https://doi.org/10.3168/jds.S0022-0302(03)73788-6

Hjalmarsson, F., Olsson, I., Ferneborg, S., Agenäs, S. & Ternman, E. (2014). Effect of low light intensity at night on cow traffic in automatic milking systems. *Animal Production Science*, 54(10), 1784–1786. https://doi.org/10.1071/AN14215

Jacobs, J. A. & Siegford, J. M. (2012). Invited review: The impact of automatic milking systems on dairy cow management, behavior, health, and welfare. *Journal of Dairy Science*, 95(5), 2227–2247. https://doi.org/10.3168/jds.2011-4943

Johnson, J. A., Paddick, K. S., Gardner, M. & Penner, G. B. (2022). Comparing steam-flaked and pelleted barley grain in a feed-first guided-flow automated milking system for Holstein cows. *Journal of Dairy Science*, 105(1), 221–230. https://doi.org/10.3168/jds.2021-20387

Ketelaar-de Lauwere, C. C., Ipema, A. H., Lokhorst, C., Metz, J. H. M., Noordhuizen, J. P. T. M., Schouten, W. G. P. & Smits, A. C. (2000). Effect of sward height and distance between pasture and barn on cows' visits to an automatic milking system and other behaviour. *Livestock Production Science*, 65(1–2), 131–142. https://doi.org/10.1016/S0301-6226(99)00175-X

King, M. T. M., Pajor, E. A., LeBlanc, S. J. & DeVries, T. J. (2017). Cow-level associations of lameness, behavior, and milk yield of cows milked in automated systems. *Journal of Dairy Science*, 100(6), 4818–4828. https://doi.org/10.3168/jds.2016-12281

Kogima, P. A., Diesel, T. A., Vieira, F. M. C., Schogor, A. L. B., Volpini, A. A., Veloso, G. J., Ferraz, P. F. P. & Zotti, M. L. A. N. (2022). The welfare of dairy cows in pasture, free stall, and compost barn management systems in a Brazilian subtropical region. *Animals*, 12(17), 2215. https://doi.org/10.3390/ani12172215

Kozlowska, H., Sawa, A. & Neja, W. (2013). Analysis of the number of cow visits to the milking robot. *Acta Scientiarum Polonorum Zootechnica*, 12(3), 37–47.

Lexer, D., Hagen, K., Palme, R., Troxler, J. & Waiblinger, S. (2009). Time budget and adrenocortical activity of cows milked in a robot or a milking parlour: interrelationships and influence of social rank. *Animal Welfare*, 18(1), 73–80. https://doi.org/10.1017/S0962728600000087

Mangalis, M., Priekulis, J. & Vernavs, G. (2021). Research on cow traffic in facilities with automatic milking systems. *Proceedings of the 20th International Scientific Conference: Engineering for Rural Development*, May 26–28, Jelgava, Latvia. https://doi.org/10.22616/ERDev.2021.20.TF041

Markey, C. (2013). *Effect of cow traffic system on cow performance and AMS capacity.* [Master's Thesis]. Swedish University of Agricultural Sciences, Uppsala Sweden.

Mathijs, E. (2004). *Socio-economic aspects of automatic milking.* In: Automatic Milking – A Better Understanding. Wageningen Academic Publishers, The Netherlands, pp. 46–55.

Matson, R. D., King, M. T. M., Duffield, T. F., Santschi, D. E., Orsel, K., Pajor, E. A., Penner, G. B., Mutsvangwa, T. & DeVries, T. J. (2021). Benchmarking of farms with automated milking systems in Canada and associations with milk production and quality. *Journal of Dairy Science*, 104(7), 7971–7983. https://doi.org/10.3168/jds.2020-20065

Mattachini, G., Bava, L., Sandrucci, A., Tamburini, A., Riva, E. & Provolo, G. (2017). Effects of feed delivery frequency in different environmental conditions on time budget of lactating dairy cows. *Journal of Dairy Research*, 84(3), 272–279.https://doi.org/10.1017/S0022029917000310

Mattachini, G., Pompe, J., Finzi, A., Tullo, E., Riva, E. & Provolo, G. (2019). Effects of feeding frequency on the lying behavior of dairy cows in a loose housing with automatic feeding and milking system. *Animals*, 9(4), 121. https://doi.org/10.3390/ani9040121

Melin, M., Pettersson, G., Svennersten-Sjaunja, K. & Wiktorsson, H. (2007). The effects of restricted feed access and social rank on feeding behavior, ruminating and intake for cows managed in automated milking systems. *Applied Animal Behavior Science*, 107(1–2), 13–21. https://doi.

org/10.1016/j.applanim.2006.09.026
Melin, M., Hermans, G., Pettersson, G. & Wiktorsson, H. (2006). Cow traffic in relation to social rank and motivation of cows in an automatic milking system with control gates and an open waiting area. *Applied Animal Behavior Science*, 96(3–4), 201–214. https://doi.org/10.1016/j.applanim.2005.06.013
Menajovsky, S. B., Walpole, C. E., DeVries, T. J., Schwartzkopf-Genswein, K. S., Walpole, M. E. & Penner, G. B. (2018). The effect of the forage-to-concentrate ratio of the partial mixed ration and the quantity of concentrate in an automatic milking system for lactating Holstein cows. *Journal of Dairy Science*, 101(11), 9941–9953. https://doi.org/10.3168/jds.2018-14665
Moreira, T. F., Nicolino, R. R., Meneses, R. M., Fonseca, G. V., Rodrigues, L. M., Facury Filho, E. J. & Carvalho, A. U. (2019). Risk factors associated with lameness and hoof lesions in pasture-based dairy cattle systems in southeast Brazil. *Journal of Dairy Science*, 102(11), 10369–10378. https://doi.org/10.3168/jds.2018-16215
Munksgaard, L., Rushen, J., Passillé, A. M. & Krohn, C. C. (2011). Forced versus free traffic in an automated milking system. *Livestock Science*, 138(1–3), 244–250. https://doi.org/10.1016/j.livsci.2010.12.023
Oberschätzl-Kopp, R., Haidn, B., Peis, R., Reiter, K. & Bernhardt, H. (2016). Studies on dairy cow behaviour with automatic feeding in a herd milked by an AMS. *Landtechnik*, 71(2), 55–65. https://doi.org/10.15150/lt.2016.3122
Paddick, K. S., DeVries, T. J., Schwartzkopf-Genswein, K., Steele, M. A., Walpole, M. E. & Penner, G. B. (2019). Effect of the amount of concentrate offered in an automated milking system on dry matter intake, milk yield, milk composition, ruminal digestion, and behavior of primiparous Holstein cows fed isocaloric diets. *Journal of Dairy Science*, 102(3), 2173–2187. https://doi.org/10.3168/jds.2018-15138
Pitkäranta, J., Kurkela, V., Huotari, V., Posio, M. & Halbach, C. E. (2019). Designing automated milking dairy facilities to maximize labor efficiency. *Veterinary Clinics of North America: Food Animal Practice*, 35(1), 175–193. https://doi.org/10.1016/j.cvfa.2018.10.010
Rodenburg, J. (2017). Robotic milking: Technology, farm design, and effects on work flow. *Journal of Dairy Science*, 100(9), 7729–7738. https://doi.org/10.3168/jds.2016-11715
Rodenburg, J. (2002). Robotic milkers: What, where... and how much!!?? *Proceedings of Ohio Dairy Management Conference*, December 16–17, Columbus, Ohio.
Rodenburg, J. & House, H. K. (2007). Field observations on barn layout and design for robotic milking. *Sixth International Dairy Housing Conference Proceeding*, June 16–18, Minneapolis, Minnesota. https://doi.org/10.13031/2013.22804
Rotz, C. A., Coiner, C. U. & Soder, K. J. (2003). Automatic milking systems, farm size, and milk production. *Journal of Dairy Science*, 86(12), 4167–4177. https://doi.org/10.3168/jds.S0022-0302(03)74032-6
Salfer, J. A., Minegishi, K., Lazarus, W., Berning, E. & Endres, M. I. (2017). Finances and returns for robotic dairies. *Journal of Dairy Science*, 100(9), 7739–7749. https://doi.org/10.3168/jds.2016-11976
Salfer, J. A., Siewert, J. M. & Endres, M. I. (2018). Housing, management characteristics, and factors associated with lameness, hock lesion, and hygiene of lactating dairy cattle on Upper Midwest United States dairy farms using automatic milking systems. *Journal of Dairy Science*, 101(9), 8586–8594. https://doi.org/10.3168/jds.2017-13925
Schwanke, A. J., Dancy, K. M., Neave, H. W., Penner, G. B., Bergeron, R. & DeVries, T. J. (2022). Effects of concentrate allowance and individual dairy cow personality traits on behavior and production of dairy cows milked in a free-traffic automated milking system. *Journal of Dairy Science*, 105(7), 6290–6306. https://doi.org/10.3168/jds.2021-21657
Siewert, J. M., Salfer, J. A. & Endres, M. I. (2019). Milk yield and milking station visits of primiparous versus multiparous cows on automatic milking system farms in the Upper Midwest United States. *Journal of Dairy Science*, 102(4), 3523–3530. https://doi.org/10.3168/jds.2018-15382
Solano, L., Halbach, C., Bennett, T. B. & Cook, N. B. (2022). Milking time behavior of dairy cows in a free-flow automated milking system. *JDS Communications*, 3(6), 426–430. https://doi.org/10.3168/jdsc.2022-0243
Thune, R. Ø., Berggren, A. M., Gravås, L. & Wiktorsson, H. (2002). Barn layout and cow traffic to optimise the capacity of an automatic milking system. *Proceedings of The First American Conference on Robotic Milking*, March 20–22, Toronto, Canada.
Tremblay, M., Hess, J. P., Christenson, B. M., McIntyre, K. K., Smink, B., van der Kamp, A. J., de Jong, L. G. & Döpfer, D. (2016). Factors associated with increased milk production for automatic milking systems. *Journal of Dairy Science*, 99(5), 3824–3837. https://doi.org/10.3168/jds.2015-10152
Tse, C., Barkema, H. W., DeVries, T. J., Rushen, J. & Pajor, E. A. (2017). Effect of transitioning to automatic milking systems on producers' perceptions of farm management and cow health in the Canadian dairy industry. *Journal of Dairy Science*, 100(3), 2404–2414. https://doi.org/10.3168/jds.2016-11521
Tse, C., Barkema, H. W., DeVries, T. J., Rushen, J. & Pajor, E. A. (2018a). Impact of automatic milking systems on

dairy cattle producers' reports of milking labour management, milk production and milk quality. *Animal*, 12(12), 2649−2656. https://doi.org/10.1017/S1751731118000654

Tse, C., Barkema, H. W., DeVries, T. J., Rushen, J., Vasseur, E. & Pajor, E. A. (2018b). Producer experience with transitioning to automatic milking: Cow training, challenges, and effect on quality of life. *Journal of Dairy Science*, 101(10), 9599−9607. https://doi.org/10.3168/jds.2018-14662

Unal, H., Kuraloglu, H., Koyuncu, M. & Alibas, K. (2017). Effect of cow traffic type on automatic milking system performance in dairy farms. *Journal of Animal and Plant Sciences*, 27(5), 1454−1463.

Unal, H. & Kuraloglu, H. (2015). Determination of operating parameters in milking robots with free cow traffic. *Proceedings of the 20th International Scientific Conference: Engineering for Rural Development*, May 26−28, Jelgava, Latvia.

Urbonavicius, G., Antanaitis, R., Zilaitis, V., Tusas, S., Kajokiene, L., Zymantiene, J., Spancerniene, U., Gavelis, A., Juskiene, V. & Juozaitienė, V. (2020). The influence of lameness on several automatic milking system variables and reproductive performance indicators in dairy cows. *Polish Journal of Veterinary Sciences*, 23, 383−390. https://doi.org/10.24425/pjvs.2020.134682

Van den Borne, B. H. P., Villalobos, A. M. G. & Hogeveen, H. (2022). Disentangling the relationships between lameness, milking frequency and milk production in Dutch dairy herds using an automatic milking system. *Preventive Veterinary Medicine*, 208, 105733. https://doi.org/10.1016/j.prevetmed.2022.105733

Vijayakumar, M., Park, J. H., Ki, K. S., Lim, D. H., Kim, S. B., Park, S. M., Jeong, H. Y., Park, B. Y. & Kim, T. I. (2017). The effect of lactation number, stage, length, and milking frequency on milk yield in Korean Holstein dairy cows using automatic milking system. *Asian-Australasian Journal of Animal Science*, 30(8), 1093−1098. https://doi.org/10.5713/ajas.16.0882

Westin, R., Vaughan, A., Passillé, A. M., DeVries, T. J., Pajor, E. A., Pellerin, D., Siegford, J. M., Vasseur, E. & Rushen, J. (2016). Lying times of lactating cows on dairy farms with automatic milking systems and the relation to lameness, leg lesions, and body condition score. *Journal of Dairy Science*, 99(1), 551−561. https://doi.org/10.3168/jds.2015-9737