Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Faculty of Veterinary Medicine and Animal Science
Department of Clinical Sciences

Effect of cow traffic system on cow performance and AMS capacity

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Abstract

Robotic milking in Automatic Milking systems (AMS) is proposed to reduce manual labour and at the same time increase milk yield by increasing milking frequency. In order to increase milking frequency, it is essential to have well-functioning cow traffic. Investing in an AMS is a great capital investment for the farmer, thus it is of major importance to ensure maximal AMS capacity. This study investigated the effect of the traffic systems Feed First™ and Free cow traffic with and without waiting area (WA) on cow performance and AMS capacity. The effects were estimated with multivariable linear regression models, accounting for other potentially influencing factors. The farmers' satisfaction with the traffic systems was investigated as well as how often and how many cows that were fetched to the milking unit and how much time the farmers spent on fetching cows to the milking unit. Data was collected from 165 dairy farms in Denmark and the Netherlands for the period 1st July 2011 to 1st July 2012. The data was retrieved from the management systems on each farm as well as from a telephone based quantitative interview with the farmers.

Cows in Feed First traffic produced on average 0.6 kg less milk per day compared to cows in Free cow traffic with WA and 0.7 kg less milk per day compared to cows in Free cow traffic without WA ($p<0.001$). Cows in Feed First traffic produced on average 0.1 kg less milk per milking compared to cows in Free cow traffic with WA ($p<0.05$). On average, cows in Feed first traffic visited the milking unit 0.1 less times per day compared to cows in Free cow traffic with and without WA ($p<0.001$). Descriptive data showed that average milking duration per robot and day was 16.6 h, 17.1 h and 16.7 h in Feed First, Free cow traffic with WA and Free cow traffic without WA respectively. Average amount of milk per robot day was 1529.8 kg, 1583.7 kg and 1550.6 kg for Feed First, Free cow traffic with WA and Free cow traffic without WA respectively. Feed First traffic resulted in on average 138.1 milkings per robot and day whereas Free cow traffic with and without WA resulted in 142.2 and 140.4 milkings per robot and day respectively. The estimates from the statistical model, i.e. adjusted for the potential effects of other variables in the model, showed that Feed First traffic resulted in 5.6 fewer visits per robot and day compared to Free cow traffic without WA ($p<0.05$). Average number of cows per robot was 55 in Feed First traffic and Free cow traffic with WA and 54.1 in Free cow traffic without WA ($p<0.001$). Farmers with Feed First traffic reported that they fetched cows on average 1.5 times per VMS and day compared to 2.5 in Free cow traffic with WA ($p<0.001$) and 2.3 in Free cow traffic without WA ($p<0.05$). Farmers in Feed First traffic also reported that they fetched on average 16.6 cows per VMS and day compared to 24.0 in Free cow traffic with WA ($p<0.05$). In terms of cow performance, Free cow traffic seems to be more favourable than Feed First traffic. Weather the differences are due to actual differences in traffic systems or management is hard to determine with the information available. Several management factors, such as feeding strategy, determine the success of cow traffic. These factors might be more important in order to obtain successful cow traffic than type of traffic system. More research, taking these factors into account, is needed to investigate the question further and to confirm the results in this study.

Sammanfattning

Robotmjölkning med hjälp av Automatiska MjölkningsSystem (AMS) anses kunna minska det manuella arbetet och samtidigt öka mjölkningsfrekvensen. För att öka mjölkningsfrekvensen krävs en väl fungerande kotrafik. Att investera i ett AMS innebär en omfattande kostnad för lantbrukaren och det är av största vikt att AMSens maximala kapacitet utnyttjas. Denna studie har undersökt effekten av trafiksystemen Feed First™ och Fri kotrafik med och utan väntfålla på kors mjölkproduktion, antal mjölkningar och mjölkkonduktivitet samt AMSens kapacitet. Analyserna har utförts med multivariabel linjär regression, där även andra faktorer som kan påverka utfallet har tagits hänsyn till. Lantbrukarnas belåtenhet med trafiksystemen samt hur ofta och hur många kor som hämtades till roboten och tidsåtgången för detta undersöktes. Data inhämtades från 1165 mjölkgårdar i Danmark och Nederländerna för perioden från 1 juli 2011 till 1 juli 2012. Datan inhämtades från gårdarnas managementsystem samt från telefonbaserade intervjuer med lantbrukarna.

Kor i Feed First trafik producerade i genomsnitt 0,6 kg mindre mjölk per dag jämfört kor i Fri kotrafik med väntfålla och 0,7 kg mindre mjölk per dag jämfört kor i Fri kotrafik utan väntfålla ($p<0,001$). Kor i Feed First trafik producerade i genomsnitt 0,1 kg mindre mjölk per mjölkning jämfört med kor i Fri kotrafik med väntfålla ($p<0,05$). I genomsnitt besökte kor i Feed First roboten 0,1 färre gånger per dag jämfört med kor i Fri kotrafik med och utan väntfålla ($p<0,001$). Deskriptiv data visar att den genomsnittliga mjölkningstiden per robot och dag var 16,6 h, 17,1 h and 16,7 h i respektive trafiksystem Feed First, Fri kotrafik med väntfålla och Fri kotrafik utan väntfålla. Genomsnittlig mängd mjölk per robot och dag var 1529,8 kg, 1583,7 kg och 1550,6 kg för respektive trafiksystem Feed First, Fri kotrafik med väntfålla och Fri kotrafik utan väntfålla. Feed First resulterade i genomsnitt i 138,1 mjölkningar per robot och dag medan Fri kotrafik med och utan väntfålla resulterade i genomsnitt i 142,2 och 140,4 mjölkningar per robot och dag. De uppskattade värdena från den statistiska modellen, dvs. justerade för de potentiella effekterna av andra variabler i modellen, visar att Feed First trafik resulterade i 5,6 färre mjölkningar per robot och dag i jämförelse med Fri kotrafik utan väntfålla ($p<0,05$). Genomsnittligt antal kor per robot var 55.8 i Feed First och Fri kotrafik med väntfålla och 54.1 i Fri kotrafik utan väntfålla ($p<0,001$). Lantbrukare med Feed First trafik rapporterade att de hämtade kor till roboten i genomsnitt 1,5 gånger per robot och dag jämfört med 2,5 i Fri kotrafik med väntfålla ($p<0,001$) och 2,3 i Fri kotrafik utan väntfålla ($p<0,05$). Lantbrukare med Feed First trafik rapporterade även att de hämtade i genomsnitt 16,6 kor per robot och dag till roboten jämfört med 24,0 i Fri kotrafik med väntfålla ($p<0,05$). Fri kotrafik verkar vara bättre än Feed First trafik i fråga om kors mjölkproduktion och antal mjölkningar. Huruvida skillnaderna beror på faktiska skillnader mellan trafiksystemen eller i management är svårt att avgöra på basis av den information som fanns tillgänglig. Flera managementfaktorer, så som utfodringsstrategi, verkar vara avgörande för en lyckad kotrafik. Dessa kan tänkas vara av större betydelse för en framgångsrik kotrafik än själva trafiksystemet. Vidare forskning, som tar hänsyn till dessa faktorer, krävs för att utreda frågan vidare och bekräfta resultaten i denna studie.

Introduction

Robotic milking in automatic milking systems (AMS) has been commercially available in Europe since 1992 (de Koning *et al.,* 2002) and is becoming increasingly common in dairy farms, especially in Europe and North America (Borderas *et al.*, 2008). The system is proposed to reduce manual labour and at the same time increase milk yield by increasing milking frequency (Rossing *et* al., 1997; Melin *et al*., 2005; Borderas *et al.,* 2008; Pettersson *et al.,* 2011). Several studies have shown the positive effects that more frequent milkings can have on milk production (Österman & Bertilsson, 2003; Melin *et al*., 2005; Pettersson *et al.*, 2011). However, automatic milking does not automatically lead to increased milk production. Unpublished data from a study by Löf (2013) show that the average Swedish farm experiences a drop in production up to five years after changing from conventional milking to AMS. In order to obtain the advantages that an AMS can provide, it is crucial to have well-functioning cow traffic with cows voluntarily visiting the milking unit (de Koning *et al*., 2002; Svennersten-Sjaunja & Pettersson, 2008). This is also important for maximum utilization of the AMS (Džidić *et al*., 2001). Investing in an AMS is a great capital investment for the farmer (Castro *et al.,* 2012; Priekulis & Laurs, 2012). Thus, it is of major importance to ensure maximal AMS capacity by maximizing the occupation rate of the robot and thereby minimizing its idle time.

The term cow traffic refers to the way that the cows can move in the barn in order to perform daily activities such as feeding, lying down and milking (Forsberg, 2008). The traffic is driven by cows' motivation to perform these activities. Eating and resting are two basic behaviours that are important in animals' self-maintenance (Fraser, 1983). Thus, to integrate milking in the daily eating and resting pattern of cows by placing the robot between the feeding and resting area causes minimal disruption to the cows' time budgets (Metz & Ketelaar-de Lauwere, 1995).

Studies have showed that cows' motivation to be milked is rather low and highly variable between individuals. Thus, this alone cannot ensure enough voluntary visits to the milking unit. Instead the strongest motivating force that drives the cow traffic in an AMS is feed (Prescott *et al.,* 1998; de Koning *et al*., 2002). Contrary to this, although Melin *et al.* (2006) acknowledge that feed is the main reason why cows visit the milking unit they also found that cows probably find milking to be rewarding. Additionally, although the cow is motivated to reach the feed, she might be reluctant to move away from the lying area because of factors such as lameness or uncomfortable flooring (Munksgaard *et al*., 2011), thus also these factors must be considered when optimizing cow traffic.

When AMS was first introduced to commercial dairy herds, Free and forced cow traffic systems were practiced (Forsberg, 2008). In Free cow traffic, the cows are not guided to the robot in any way. Instead the cows can move freely in the barn and thus go to the feeding or lying area without passing the milking unit (Thune *et al.*, 2002). In forced cow traffic on the other hand, the cows have to go via the milking unit in order to reach the feed. After feeding, cows are directed to the lying area through one-way gates. Several studies have investigated the effect of Free and forced cow traffic systems in barns with AMS (Ketelaar-de Lauwere *et al.,* 1998; 2000; Harms *et al*., 2002; Thune *et al.*, 2002; Bach *et al.*, 2009). According to these studies forced cow traffic ensures more frequent visits to the milking unit. However, this traffic system has been questioned since it interferes with the cows' ability to control and synchronize their daily activities with the rest of the herd and may thereby impair animal welfare (Winter & Hillerton, 1995; Ketelaar-de Lauwere, 1998). Furthermore, as the cows have to go via the milking unit in order to reach the feed the system might result in fewer visits to the feeding area (Ketelaar-de Lauwere *et al.*, 2000; Harms *et al.*, 2002; Thune *et al.*, 2002; Bach *et al.*, 2009). This can in turn lead to reduced feed intake (Melin *et al.*, 2007) as well as unnecessary occupation of the robot (Rossing *et al*., 1997; Munksgaard *et al*., 2011). Therefore, the use of forced cow traffic has decreased, often replaced by Feed First™ or Milk First traffic systems, referring to feed before milking or milk before feeding. The differences in production performance of cows in systems with Free cow traffic or systems with Feed First or Milk First have however not yet been fully investigated. Since the success of the cow traffic system highly affects the production of cows housed in an AMS this is of great interest.

The objective of this study was to investigate how the cow traffic systems Free cow traffic with and without waiting area (WA) and Feed First affect cow performance and AMS capacity. Cow performance was expressed as milk yield per cow and day, milk yield per cow and milking, number of milkings per cow and day and milk conductivity. System capacity was expressed as number of cows per robot, duration of milking time, amount of milk per robot and day and number of milkings per robot and day. Furthermore, the study investigated how pleased the farmers were with the different traffic solutions as well as their milking system. The study also investigated how often and how many cows that were fetched to the milking unit as well as the time the farmers spent on fetching cows to the milking unit in the different systems.

Literature review

Cow traffic systems

From the beginning, the systems Free, forced and selective cow traffic with selection gates were in use in commercial dairy herds. However, subsequently the guided systems Milk First and Feed First, which is a combination of Free and selective cow traffic, have been developed (Forsberg, 2008).

Selective cow traffic

In selective cow traffic with selection gates the cows can enter the feeding area either via the milking unit or via a controlling gate. Cows with milking permission[1] are denied entrance to the feeding area via the controlling gate and have to pass the milking unit in order to reach the feed (Forsberg, 2008).

Milk First

In a Milk First system the selection gate is instead placed in front of the milking unit and all cows have to go through the gate in order to reach the feeding area. The selection gate directs the cows to the milking station or the feeding area depending on if they have milking permission or not. If the cow has permission to be milked she is directed to the WA in front of the milking unit. If the cow has no milking permission, she is directed straight to the feeding area (Rossing *et al.*, 1997). From the feeding area, the cows have free access to the lying area by one way gates.

[1] Allows the cow access to the milking unit. Milking permission is established by the management system based on certain criteria such as expected yield and success of last milking. The time interval between milkings is set either manually by the farmer or automatically by the management system.

Since this study concerns the traffic solutions Free cow traffic and Feed First mainly these two systems will be discussed in the following review.

Feed First

A Feed First system has the same layout as a Milk First system, except that access to the lying area is controlled instead of to the feeding area. Thus, the cows have free access to the feeding area by one way gates from the lying area. However, in order to reach the lying area from the feeding area, the cows have to pass a selection gate that directs the cows to the milking station or the lying area depending on the milking permission. If the time since last milking is long enough and a milking permission has been established the cow is directed to the WA in front of the milking unit. If the cow has no milking permission, she is directed back to the lying area.

According to Metz (1985), lying is an important behaviour for which the cows show strong motivation. In a Feed First system, the traffic is driven by the cows' motivation to feed and thus visit the feeding area. After feeding the cows' motivation to lie down ensures attendance to the milking unit. In some cases, concentrate feeders are placed in the lying area in order to motivate the cows even further. To our knowledge there seems to be few or no studies done concerning the effect of Feed First cow traffic on cow performance and AMS capacity which highlights the need of such an investigation.

Free cow traffic

In a Free cow traffic system, the cows are not guided to the robot in any way. Instead the cows can move freely in the barn and thus go to the feeding or lying area without passing the milking unit (Thune *et al.,* 2002). In this system, the cows are encouraged to visit the milking unit by being offered concentrates in the robot (Rossing *et al*., 1997; Prescott *et al*., 1998; Hermans *et al*., 2003). The system has shown to be especially favourable for low-ranked cows with regard to time spent waiting in front of the milking unit (Thune *et al., 2002;* Lexer *et al*., 2009). On the other hand, Free cow traffic is argued to cause problems with cows attending the robot too infrequently (Ketelaar-de Lauwere, 1998; Ketelaar-de Lauwere & Ipema, 2000; Bach *et al.,* 2009). This can in turn have a negative effect on milk production (Jacobs & Siegford, 2012a).

One problem with Free cow traffic is that cows with the intention to visit the milking unit might withdraw and perform some other activity if the robot is occupied (Ketelaar-de Lauwere *et al.,* 2000). This can be avoided by placing a WA in front of the milking unit where cows will have to remain until they have passed the unit (Uetake *et al*., 1997). A study by Neijenhuis *et al*. (2010) showed that a WA in front of the milking unit was associated with better udder health in terms of lower SCC. Although reasons for this were not clear, this might have been a result of shorter or more even milking intervals (Hovinen & Pyörälä, 2011). However, a WA might result in other consequences and a study by Ketelaar-de Lauwere *et al.* (2000) showed that cows in Free cow traffic systems with a closed WA, i.e. a WA from which the only exit is via the milking unit, spent less time in the feeding area compared to cows in Free cow traffic without a WA. Furthermore, cows spent more time in the AMS area, i.e. the area from the entrance of the selection system to the exit of the AMS, in Free cow traffic with WA compared to Free cow traffic without WA. This subsequently slowed down the passage through the AMS which is unfavourable in terms of AMS capacity (Ketelaar-de Lauwere *et al.,* 2000). Furthermore, although Thune *et al.* (2002) argues that long waiting times might not necessarily be a problem, cows standing for too long periods could lead to irregular milkings and impaired animal welfare (Harms *et al.,* 2002). Prolonged waiting in anticipation of milking might also inhibit the milk let-down response and thereby cause impaired milk yield as well as longer milking times (Winter & Hillerton, 1995). Varlykov and Tossev (1992) reported an upper waiting time for normal milk release of 30 minutes. When the waiting time reached 40 minutes, the milking times increased significantly. Furthermore, long standing time is also predisposing for claw disorders (Blowey, 2005; Barker *et al.,* 2008).

Milking intervals

Milk yield

One of the main advantages with AMS is the possibility to increase milking frequency, i.e decrease milking intervals, without major increase in labour input (Ipema, 1997; Svennersten-Sjaunja & Pettersson, 2008). By increasing the number of milkings from two to three times per day, the lactation milk yield can be increased by 10-15 % (Klei *et al.,* 1997; Österman & Bertilsson, 2003). However, higher attendance at the AMS than four times per day does not increase milk yield significantly but rather reduces the efficiency of the robot (Laurs *et al.,* 2008). Other researchers have failed to establish a positive effect of increased milking frequencies (Abeni *et al*., 2005, 2008; Gygax *et al*., 2007) in particular in primaparous cows (Abeni *et al.,* 2005, 2008). Milking frequencies of at least two times per day, and higher for high yielding cows, are in any case desirable and thus, milking intervals should not exceed 12 hours (Svennersten-Sjaunja & Pettersson, 2008).

One suggested reason for lower milk production as a result of long milking intervals is decreased mammary blood flow which in turn down-regulates the udders' ability to extract nutrients from the blood (Delamaire & Guinard-Flament, 2006a, b; Guinard-Flament *et al.,* 2007). Furthermore, longer milking intervals appears to alter mammary epithelial integrity which also might be an explanation to the lower milk yield (Sorensen *et al.,* 2001; Delamaire & Guinard-Flament, 2006b). The extraction of glucose and protein precursors is more regulated than the extraction of fat precursors. Hence, the decrease in milk yield, resulting from the decrease in glucose, and the decline in protein content is more evident than the decline in milk fat (Delamaire & Guinard-Flament, 2006b).

Milk quality

Increased number of milkings can also enhance milk processing quality. According to Sorensen *et al*. (2001) a shorter storage time in the udder reduces the exposure of milk to proteolytic enzymes and thereby increases the proportion of casein in total protein. However, contradictive to this, in a study by Klei *et al.* (1997) a milking frequency of three milkings per day generally resulted in lower casein percentage than a milking frequency of two milkings per day, even though the result was only significant in early lactation. In that study, cows that were milked three times per day throughout the entire lactation had 4.7 and 7.3% higher fat and protein yields, respectively, compared to cows that were milked two times per day. However, too frequent milkings increases the amount of free fatty acids in the milk, possibly as a result of increased de novo synthesis of short chain fatty acids (Klei *et al*., 1997).

Udder health and animal welfare

More frequent milkings has generally been associated with less mastitis (Hovinen & Pyörälä, 2011) and studies have showed evidence of reduced milk somatic cell count (Klei *et al.*, 1997; Berglund *et al*., 2002) as well as electrical conductivity (Fernando & Spahr, 1983) as a result of increased milking frequency. Measuring electrical conductivity in milk has been reported to be a successful way to detect subclinical mastitis in cows (Fernando *et al*., 1982). When using this technique, udder quarters should be compared with each other and a large inter-cow variation has to be kept in mind (Sandholm *et al.,* 1995).

This effect is probably due of more frequent wash-out of pathogens (Hovinen & Pyörälä, 2011). The study by Fernando & Spahr (1983) showed that the electrical conductivity in milk was as highest at a 3 h interval but declined to its lowest at 9 h interval. Between intervals of 9 to 15 h, the conductivity steadily increased. However, too frequent milkings can have a negative effect on udder health. Ipema & Benders (1992) found that an increased milking frequency to four times per day increases the erosion and eruption to the teat ends which in turn can increase the risk of mastitis. Neijenhuis *et al.* (2001) stated that recovery of the teats after milking might take up to 8 hours which suggests that in terms of udder health, milking intervals should not be shorter than 8 hours. According to this, the optimal milking frequency is three times per day. Further, the risk of pathogens entering the udder is greatest after milking when the teat channel is still open (Hillerton, 1991). More milkings increases the number of periods during which there is a high risk of pathogen invasion into the mammary gland, which also increases the risk of mastitis (Hogeveen *et al.,* 2001).

Moreover, decreased pressure in the udder, as a result of increased milking frequency, seems to improve the cows' ability to move, for example when standing up and lying down during the hours before milking. Thus, the animal welfare is considered to be improved (Österman & Redbo, 2001).

Milking intervals in AMS

The milking frequency in an AMS is dependent on the number of cows and their performance, i.e. the daily amount of milk in the AMS. Thus, the number of milkings per cow declines with increasing number of cows per robot and increasing amount of milk (Artmann, 2002). A study done on 153 farms with Delaval and Lely merchandised AMS and various types of traffic systems showed that the average number of milkings per cow and day was 2.41 for cows in herds with DeLaval Voluntary Milking System (VMS) and 2.8 for cows in herds with Lely AMS (Andersson *et al.*, 2013). Among the farms that participated in the study Feed First and Milk First traffic was most common on farms with DeLaval Voluntary Milking System (VMS) whilst Free cow traffic was most common in Lely herds. In a study by Stefanowska *et al*. (1999a) cows in a Free cow traffic system paid on average 6.0 visits to the milking unit of which 2.8 were milking visits. In another study by Stefanowska *et al*. (1999b) the average milking frequency was 3.0 milkings per day for cows in Free cow traffic without WA and 2.9 milkings per day for cows in Free cow traffic with WA. However, these studies only included 24 cows, which is far from the size of commercial AMS groups. In a study by Priekulis & Laurs (2012) on three farms with Feed First or Milk First traffic and herd sizes of 97, 94 and 108 cows served by two DeLaval AMS, the average number of visits to the milking unit was 2.7 times a day, which according to the authors can be considered relatively successful. These results are similar to those found in other studies on cows in Free cow traffic where the average number of milkings per cow and day were 2.69 for on average 52.9 cows (Castro *et al.* 2012), 2.76 to 2.88 for the small group of 10 to 29 cows (Džidić *et al*., 2001) and 2.6 for on average 66 cows (Hogeveen *et al.,* 2001).

Although most of the milking intervals in an AMS seem to lie in the range 7-9 h, considerable variation in milking interval within herds has been reported (Hogeveen *et al*., 2001; Abeni *et al*., 2005; Gygax *et al*., 2007). In a study by Gygax *et al*., (2007), 11.5% of the milking intervals were shorter than 6 hours whereas 21% were longer than 12 hours. Further, in a study by Hogeveen *et al.* (2001), although the average milking interval was 9.2 h, 27% of the intervals were <6 h or >12 h and 17.6 of the milking interval were >12 h. Irregular milkings can lead to decreased milk yield although some of the variation is likely to be a natural result of stage of lactation (Jacobs & Siegford. 2012a). According to a study by Pettersson *et al.* (2011), milking frequency decreases with increasing stage of lactation. However, the author of the study also claims that this can be prevented with good management.

Fetching cows to the AMS

Cows that do not visit the AMS frequent enough have to be brought to the milking unit manually by the farmer. This is time-consuming and could be the one of the largest factor preventing farmers to decrease their labour as much as expected when converting to AMS (Bach *et al.,* 2007). Fetching is most frequent during the first month of lactation when the cows have to acclimatise to and learn the new system day. In a study by Jacobs & Siegford (2012b) 60% of the cows were milking voluntarily after the first week in lactation and after two weeks of lactation 75% of the cows attended the milking without having to be fetched. One month after the introduction to the AMS, when the cows have learnt how to move in the system, 95% of the cows attended milking voluntarily. In a Canadian survey, farmers reported that they fetched on average 4 to 25% of the cows. However, there was a major variation between herds. The five farms that fetched least cows fetched on average 2.5% of the cows, whereas the five farms that fetched most cows reported that they fetched on average 41.6% of the cows once or twice daily. Farms with Free cow traffic reported that they fetched on average 16.2 of the cows while farms with some kind of guided traffic (i.e. forced traffic or traffic with selection gates) fetched on average 8.52 % cows once or twice daily (Rodenburg & House, 2007).

A study by Rousing *et al.* (2006) revealed that cows that had to be fetched to the AMS showed a greater avoidance distance[2] when approached by a familiar person. However, whether this was due to the fact that these cows were initially more fearful or that they kept the distance in order to avoid being brought to the AMS is unclear. The study could not establish any significant differences in cows' reluctance to enter the AMS or the amount of stepping and kicking in the AMS between cows that had to be fetched and cows that visited the AMS voluntarily.

Feeding for optimal cow traffic

Dairy cows are mainly diurnal feeders that, under normal circumstances, eat during the day and rest at night (Winter & Hillerton, 1995). However, several studies have shown that milkings in AMS are more or less evenly distributed over 24 hours, with a slight decrease in attendance in early mornings (Stefanowska *et al*., 1999ab; Hogeveen *et al*., 2001; Munkgaard *et al.,* 2011). Since feeding is the main attraction for cows to attend the milking unit, any changes in feeding management that affect the feeding pattern of the cows will subsequently affect the cow traffic (Melin, 2005). More frequent feedings of totally mixed ration (TMR) can increase the visits to the milking unit (Rodenburg & Wheeler, 2002). However, according to Rodenburg and Wheeler (2002), the frequency with which stale feed was pushed back to the feeding table did not affect the attendance to the milking unit. Thus, also the palatability of the feed seems to be of importance. Also, the type of feed can affect cow traffic. In a study by Rodenburg and Wheeler (2002), there were strong associations between high energy and low forage intake and a decreased attendance to the milking unit.

[2] The distance at which the cow avoids the approach, i.e. steps away from the approaching human.

The availability of feed is important because lack of feed during parts of the day will increase the synchronized eating and resting behaviour among cows. This will in turn result in disturbed cow traffic with more queuing in the WA, longer and more variation in milking intervals as well as an increased need for fetching cows to the milking unit (Forsberg, 2008; Svennersten-Sjaunja & Pettersson, 2008).

Concentrate allocation is a good way to attract cows to the milking unit. The ration should however be limited to about 3.5 kg per visit (Ipema, 1997). Especially for cows with large daily rations, feeding only during milking might lead to insufficient time to consume the feed (Ketelaar-de Lauwere *et al*., 1999). According to Ipema (1997), 12 minutes is required in order for a cow to consume 3.5 kg concentrate. Since the milking duration often will be close to 7 minutes, especially for cows with high milking frequency (pers. com., Ter Weele, 2013), the concentrate intake might be impaired. Furthermore, high amounts of concentrate fed few times per day increases the risk of rumen acidosis (Owens *et al.,* 1998) as well as claw disorders such as sole ulcers (Manske *et al.*, 2002). One solution to this is to use separate concentrate feeders. The feeders can be located in such a way that the cows can reach them only by passing the AMS which encourages the cows to visit the milking unit. This does however lead to fewer visits to the feeders as well as more feed left compared to if the cows have free access to the concentrate feeders (Ketelaar-de Lauwere *et al*., 1999). Therefore, free access to concentrate feeders with individual settings according to the maximum amount of feed might be preferable.

AMS capacity

Milking system capacity is often expressed as number of milkings per day (de Koning *et al.,* 2002; Castro *et al.,* 2012) or kg milk per day (Castro *et al.,* 2012). However, since the handling time per milking is more or less fixed and increased milking frequency leads to lower milk yield per milking, increased number of milkings per day does not necessary go hand in hand with a higher capacity when this is expressed as kg milk per day (de Koning *et al.,* 2002). A Swedish study by Andersson *et al.* (2013) showed that the average number of milkings per robot and day was 153 for both DeLaval and Lely AMS's. Average amount of milk delivered to the milk tank per robot and day was 1719 kg, with values ranging from 900 kg to 2500 kg per robot and day (Andersson *et al.,* 2013).

Number of milkings depends on several factors in the configuration of the milking system, such as number of milking stalls, milking frequency, machine on time, herd size and cow traffic system (de Koning *et al.,* 2002). Amount of milk per day on the other hand, is more affected by milk flow rate, yield of the cow and number of cows in the AMS group (de Koning *et al.,* 2002; Castro *et al.,* 2012). A study by Castro *et al.* (2012) revealed that by increasing the milk flow by 0.1 kg/min, for each additional cow the yearly AMS milk yield could be increased by 8,226 kg. The milk flow rate decreases with increasing milking frequency (Ipema, 1997; Hogeveen *et al*., 2001), suggesting that longer milking intervals could lead to shorter machine time and thus better utilization of the robot capacity (Ipema, 1997). On the other hand, high milk flow rates have shown to increase the risk of mastitis (Petermann *et al.,* 2002) and thus, a balance between these two factors is desirable.

Duration of milking procedure

The procedure in the milking unit should comprise cows entering the unit, teat cleaning, teat cup attachment, milking, disinfection of the teats and leaving the milking unit. All these activities should be completed as quickly as possible in order to maximize system capacity (Devir *et al.,* 1999). According to Stefanowska *et al.* (1999b) cows move through the AMS with an average speed of 0.1-0.4 m/s which is considerably slower than the average walking speed of cattle 0.6-1.0 m/s (Phillips, 2002). Stoppage (such as queuing in the WA), uncertainty, presentation of food reward, insight into surroundings are all crucial factors affecting the speed at which cows move through the AMS. Additionally, the presence of other cows affects the time that cows spend in the AMS area. Cows exiting the AMS tend to hesitate longer when other cows are near the exit gate or in the WA than when no cows are present (Jacobs *et al.,* 2012). Furthermore, in the study by Jacobs *et al.* (2012), cows in later lactation had a greater probability to hesitate when exiting the AMS compared to cows in early lactation.

In a Japanese study by Komiya *et al.* (2002) the average operational time per milking needed in order for the cow to enter, cleaning of the teats, teat detection and milking, was 7.9 min. Average operational time excluding milking was 2.9 min. The average milk yield per milking and milk flow rate in the study was 10.2 kg and 2.1 kg/minutes. In another study investing robot capacity of DeLaval produced AMS, Priekulis & Laurs (2012) found that the average milking time per cow was 7.5 min.

Optimal number of cows in an AMS

The optimal herd size served by one milking unit is influenced by factors such as milk yield, milking frequency, accessibility of a milking stall during the 24 hours and the occupation rate of the stall. More cows and a larger volume of milk produced per milking unit are associated with decreased voluntary attendance (Rodenburg & Wheeler, 2002). According to Komiya *et al.* (2002), the milking capacity expressed as the number of cows that can be milked by a robot can be calculated by following mathematical model;

$$N_{cow} = \frac{3600\, fkW_h}{y\left(ft + 60k\right)}$$

Where:
N_{cow} = Number of cows
f = Average milk flow in the herd (kg / min)
k = Average expected milk yield per milking (kg / milking)
W_h = Actual operation time on the milking robot (h / day)
y = Average daily milk yield in the herd (kg / day)
t = working time of milking robot, expected milking operation (s /cow)

The Swedish survey by Andersson *et al.* (2013) done on 109 herds with DeLaval merchandised VMS and 44 herds with Lely merchandised AMS showed that the average number of cows per robot was 63 and 56 in DeLaval herds and Lely herds, respectively. The survey also revealed that 62% of the farmers with DeLaval VMS thought that the maximum number of cows per robot was 70 or more, while 65% of the farmers with Lely AMS thought that the corresponding figure was 60-70 cows per robot. In a study on three farms, investigating the maximal number of cows that could be served by a DeLaval produced AMS, Priekulis & Laurs (2012) found that the size of the herd served by one AMS should not exceed 58-59 cows. Contradictive to this, Castro *et al.* (2012) claimed that by increasing the herd size to up to 68 cows an increase in amount of milk per AMS and year could be achieved although milking frequency decreased. According to these authors, in order to maximize the milk yield per AMS and year, the herd size should range between 59 to 68 with 2.40 to 2.60 milkings per cow and day. The studies did however differ in traffic systems as the former study included farms with Feed First or Milk First traffic whereas the latter was conducted in herds with cows in Free cow traffic. Also the manufacturer of the AMS differed between the studies.

Idle time of the AMS station

The idle time of the robot, i.e. the time that the robot is not occupied, is very much affected by the cows' willingness to visit the milking unit as well as by the number of cows in the served group, kind of cow traffic, configuration of the WA, location of the AMS etc. (Priekulis & Laurs, 2012). Cows loitering at or obstructing the entrance or exit of the milking robot system will affect the capacity negatively (Rossing *et al.,* 2002). Furthermore, even though the loading of the AMS station is maximized, the AMS cannot be used for milking the entire time of the day since some time is needed for cleaning (Castro *et al.,* 2012). In guided systems it is possible to choose to not direct cows to the WA or only direct so called "red" cows (i.e cows that have exceeded a time/expected yield limit since last milking) to the WA during cleaning of the AMS (pers. com Ter Weele, 2013). In the study by Priekulis & Laurs (2012), AMS milk line washing time was 37-42 min and milk tank washing time 20-45 min. The average cleaning time for DeLavals' VMS is close to 15 min (pers.com., Ter Weele, 2013), since the system does not need to wait for the bulk tank to be cleaned to start milking because of the DeLaval buffer vessel (BVV). The BVV collects the milk after the VMS is cleaned and ready to start milking again but the cleaning of the bulk tank is still on going. When the cleaning of the bulk tank is finished, milk is sent from the BVV to the tank and the milk from the VMS is going directly to the tank (pers.com., Ter Weele, 2013).

An occupation rate, i.e. the proportion of time that the robot is occupied with milking, of 80% was achieved in a study by Munksgaard *et al*. (2011) where the robot was occupied for on average 50 minutes per hour in a Free cow traffic system with a group size of 35 cows. However, in this study the attendance to the robot was relatively high, probably due to the small group size. Also in a study by Jacobs *et al.* (2012) a high occupation rate was achieved. Results showed that the AMS was empty 10 and 18% of the day, although also in this study the number of cows was relatively low (42 per AMS). In a study by Priekulis & Laurs (2012), with 47-58 cows per group, the AMS was occupied for milking 16-18 hours per day and for service of milk tanks and milk lines 1.5-6.2 hours per day. The AMS station was however vacant for 3.5-6.2 hours per day. The results of the occupation rate of the robot are in line with the study by Castro *et al.* (2012) where the robot was milking 72% of the day as well as with the study by Andersson *et al.* (2013) where the robot was milking 77% of the day. Although Priekulis & Laurs (2012) states that the maximal number of cows served by the AMS should be 58-59 cows, Castro *et al.* (2012) argues that by increasing the herd size from 52.9 to 68.9 cows and decreasing the milking frequency from 2.69 to 2.48 milkings per cow and day, the occupation rate of the AMS station could be increased to 94%. This is however only possible under optimal conditions considering sufficient space in the barn, maintaining the average visit time at every milking and avoiding increased competition between cows due to increase herd size (Castro *et al.,* 2012).

Material and Methods

Study population

Data was collected from 73 Danish and 92 Dutch dairy farms with one to three DeLaval merchandised VMS. The farms included in the study had one or several of the investigated cow traffic systems; Free cow traffic with WA, Free cow traffic without WA or Feed First^{TM}. Farms with Jersey cows were excluded from the study due to the breeds' lower yield. Except Jersey, cows of all breeds and parities were included. In Denmark, 19 farms with Feed First traffic, 23 with Free cow traffic with WA and 31 with Free cow traffic without WA participated (Table 1). In the Netherlands, 28 farms with Feed First traffic, 38 with Free cow traffic with WA and 26 with Free cow traffic without WA participated. In total, 47 farms with Feed First traffic, 61 with Free cow traffic with WA and 57 with Free cow traffic without WA participated (Table 1). The data includes information from 75 milking stations in Feed First traffic (36 Danish and 39 Dutch), 102 milking stations in Free cow traffic with WA (47 Danish and 55 Dutch) and 100 milking stations in Free cow traffic without WA (61 Danish and 39 Dutch). The study included data from 5 305 cows in Feed First traffic (2 674 Danish and 2 631 Dutch), 7 844 cows in Free cow traffic with WA (3 822 Danish and 4 022 Dutch) and 7 358 cows in Free cow traffic without WA (4 717 Danish and 7 358 Dutch). In total 20 507 cows were included in the study (Table 1).

Table 1. Number herds, milking stations and cows from each country and traffic system

Traffic system	Herds	Milking stations	Cows
Feed First			
Denmark	19	36	2 674
Netherlands	28	39	2 631
Total	**47**	**75**	**5 305**
Free WA[a]			
Denmark	23	47	3 822
Netherlands	38	55	4 022
Total	**61**	**102**	**7 844**
Free no WA			
Denmark	31	61	4 717
Netherlands	26	39	2 641
Total	**57**	**100**	**7 358**
Total	**165**	**277**	**20 507**

[a]WA=waiting area

Recording of data

Contacting farmers and gathering of data started in July 2012 and was completed in October 2012. A letter (Appendix 1) with information about the study and an invitation to participate was sent to selected farms. The farmers who did not respond were contacted by phone and asked whether they would like to participate. A second letter (Appendix 2) with instructions, traffic system drawings (Appendix 3) and a memory stick was sent to the farmers that agreed to participate. All data from the management tool (DelPro or VMS Management) was copied, by the farmer, to the memory stick and sent back to the project leader together with the drawings. The intention with the traffic system drawings was to verify the type of traffic system used. The farmers also participated in a telephone based quantitative interview (Appendix 4). The questions in the interview protocol were designed to embrace the production performances of interest as well as variables that might affect the results. The upper time limit for the interview was set to 15 minutes. Before starting the interviews for the study, the protocol was tested on four Danish farms with different traffic solutions.

Information about the variables concerning milk production (kg), number of milkings, duration of milking procedure (h), milk conductivity (mS/cm), number of cows served by the VMS and mean milk flow rate (kg/min) was gathered from the management tools. Information about herd and management characteristics, such as production systems, breeds, number of times fetching cows, etc, was gathered from the telephone interview. Farmers' satisfaction with the traffic system was also recorded in the interview and assessed using a 10-point likert scale (Appendix 4).

Milk conductivity was measured continuously on quarter level during the whole milking procedure. An average was calculated per quarter and these were subsequently summarized as the median for the milking. Mean milk flow was calculated on quarter level based on the time from exudation of milk in the first teat cup until the last teat cup was taken off and these were also summarized as the median for the milking. In the VMS management tool, milking duration was calculated as the time from identification of the cow to opening of the exit gate. In the DelPro management tool, milking duration was calculated as the time from identification of the cow to removal of the last teat cup. Total amount of milk per milking station and day was calculated by summarizing the amount of milk form all milking occasions during the day. Number of cows per robot was calculated as total number of cows per herd divided with total number of robots per herd.

Data handling and statistical analysis

Data from the memory sticks included observations between 1st July 2011 and 1st July 2012. A total of 83 farms had data stored from the whole period, 40 farms had data from 10<12 months, 28 farms had data from 5<10 months and 15 farms had data from less than 5 months. Parity was grouped into 1, 2 and ≥ 3. Stage of lactation was grouped into periods 0-59, 60-119, 120-219 and 220- days in milking. Season was grouped into April-October (0) and November-March (1). All statistical analyses were performed using R (R Core Team, 2012). All dependent variables were checked for normally distributed residuals. Descriptive statistics such as arithmetic averages and 1st and 3rd quantiles were calculated. The statistical significance of the differences between the farmers' satisfaction with the traffic- and milking systems as well as number of times fetching cows per day, number of cows fetched per day and time spent on fetching cows per day was determined using chi-squared analysis.

Differences in cow performance and AMS capacity, except for number of cows per VMS, between traffic systems were estimated with multivariable linear mixed regression models. The difference in number of cows per VMS between traffic systems was estimated with a simple linear regression model. The statistical model for cow performance included the fixed effects of cow traffic system (Feed First/Free cow traffic with WA/Free cow traffic without WA), season (0/1), herd size (continuous), country (Netherlands/Denmark), production system (conventional/organic), breeds (Holstein/other or mixed breeds), number of times fetching cows per day (continuous), number of cows served by the VMS (continuous), number of robots per group (continuous) and the combined effect of lactation stage and lactation number of the cow. The model included the random effects of herd, cow and robot. Due to the very large number of observations the average of the response variables per lactation number, stage of lactation and season were used as the dependent variables and the model thus included the number of observations for the average of the response variable as a weighting variable. The statistical model for robot capacity included the fixed effects of cow traffic, season, herd size, production system, breeds, country, number of times fetching cows per day, number of cows served by the VMS, number of robots per group and mean milk flow rate (0.1 kg/min) (continuous). Milk flow was not linearly associated with the outcome and thus also the squared value of milk flow was used in the model for robot capacity. The model also included the random effects of robot and herd.

The significance of the effect of average number of fetched cows per day (continuous) on the dependent variables for cow performance and AMS capacity was tested. The effect was non-significant and the variable was excluded from the models. The effect of management tool (DelPro or VMS Management) on total milking duration was also tested. The effect was non-significant and the variable was excluded from the model. The regression of herd size and milk flow was tested by investigating whether or not the squared value of herd size significantly contributed to the differences in the response variables. Number of observations per dependent variable, are presented in Table 2 and Table 3.

Table 2. Number of observations for variables concerning cow performance

Traffic system	Milk/day	Milk/milking	Milkings/day	Conductivity
Feed First				
Denmark	532 515	1 295 049	532 515	1 295 049
Netherlands	553 676	1 407 488	553 676	1 350 040
Total	**1 086 191**	**2 702 537**	**1 086 191**	**2 645 089**
Free WA[a]				
Denmark	780 549	1 941 836	780 549	1 941 836
Netherlands	848 467	2 228 704	848 467	2 108 015
Total	**1 629 016**	**4 170 540**	**1 629 016**	**4 049 851**
Free no WA				
Denmark	1 024 213	1 530 724	1 024 213	2 558 936
Netherlands	575 712	2 558 936	575 712	1 491 528
Total	**1 599 925**	**4 089 660**	**1 599 925**	**4 050 464**
Total	**4 315 132**	**10 962 737**	**4 315 132**	**10 745 404**

[a]WA=waiting area

Table 3. Number of observations for variables concerning capacity of the automatic milking system

Traffic system	Milking duration/day	Milk/day	Milkings/day
Feed First			
Denmark	1 295 136	1 295 136	1 295 136
Netherlands	1 407 558	1 407 558	1 407 558
Total	**2 702 694**	**2 702 694**	**2 702 694**
Free WA[a]			
Denmark	1 943 871	1 943 871	1 943 871
Netherlands	2 232 057	2 232 057	2 232 057
Total	**4 175 928**	**4 175 928**	**4 175 928**
Free no WA			
Denmark	2 562 231	2 562 231	2 562 231
Netherlands	1 534 375	1 534 375	1 534 375
Total	**4 096 606**	**4 096 606**	**4 096 606**
Total	**10 975 228**	**10 975 228**	**10 975 228**

[a]WA=waiting area

Results

An ANOVA with the results from the analyses of cow performance, including degrees of freedom (df) and level of significance, is presented in Table 5.

Cow performance

Milk yield per cow and day

Cows in Feed First traffic yielded on average 28.0 kg milk/day. Cows in Free cow traffic with and without WA yielded on average 28.6 and 28.5 kg milk/day, respectively (Table 4).

The estimates from the statistical model, i.e. adjusted for the potential effects of other variables in the model, showed that cows in Free cow traffic with WA produced on average 0.6 kg more milk per day than cows in Feed First traffic ($p<0.001$). Cows in Free cow traffic without WA produced on average 0.7 kg more milk than cows in Feed First ($p<0.001$). There was no significant difference in milk yield per day between Free cow traffic with and without WA (Table 5).

Milk yield per cow and milking

Cows in Feed First traffic yielded on average 11.2 kg milk/milking, while cows in Free cow traffic with and without WA yielded on average 11.1 kg milk/milking, respectively (Table 4).

The statistical analysis found that cows in Feed First traffic produced on average 0.1 less milk per milking compared to cows in Free cow traffic with WA ($p<0.05$). There was no significant difference in milk yield per milking between Free cow traffic without WA and Feed First traffic or Free cow traffic with WA (Table 5).

Number of milkings per cow and day

Average number of milkings per day for cows in Feed First traffic and Free cow traffic with and without WA was 2.5, 2.6 and 2.6 times respectively (Table 4).

When the results from the statistical model was considered, cows in Feed First traffic visited the milking unit on average 0.1 fewer times per day compared to cows in Free traffic with and without WA ($p<0.001$). There was no significant difference in number of milkings per day between Free cow traffic with and without WA (Table 5).

Milk conductivity

Average electrical conductivity in milk for cows in Feed First traffic, Free cow traffic with WA and Free cow traffic without WA was 4.6 mS/cm, 4.5 mS/cm and 4.6 mS/cm respectively (Table 4).

The statistical analysis found that cows in Free cow traffic with WA had on average 0.1 mS/cm lower milk conductivity than cows in Feed First traffic ($p<0.001$) and 0.1 mS/cm lower milk conductivity than cows in Free cow traffic without WA ($p<0.001$). Cows in Feed First had on average 0.1 mS/cm lower milk conductivity than cows in Free cow traffic without WA ($p<0.001$) (Table 5).

Table 4. Descriptive statistics, with means and 1st and 3rd quartiles (Qu), for cow performance in different cow traffic systems

Traffic system	Yield/day (kg)	Yield/milking (kg)	Milkings/day	Milk Conductivity (mS/cm)
Feed First				
Mean	27.0	11.2	2.5	4.6
1st Qu	21.3	9.1	2.1	4.3
3rd Qu	34.4	13.0	2.9	4.9
Free WA[a]				
Mean	28.6	11.1	2.6	4.5
1st Qu	22.3	9.2	2.1	4.2
3rd Qu	34.6	12.9	3.0	4.8
Free no WA				
Mean	28.5	11.1	2.6	4.6
1st Qu	22.3	9.2	2.1	4.3
3rd Qu	34.7	12.8	3.0	4.9

[a]WA=waiting area

Table 5. ANOVA with differences in cow performance, as estimated with a multivariable linear regression model, degrees of freedom (df) and level of significance

			Milk yield/day (kg)		**Milk yield/milking (kg)**		**Milkings/day**		**Milk conductivity (mS/cm)**	
Fixed factors	**Level**	**df**	**p<**	**Estimate**	**p<**	**Estimate**	**p<**	**Estimate**	**p<**	**Estimate**
Cow traffic	Feed First	2	0.05	0[Ra]	0.001	0[Ra]	0.001	0[Ra]	0.001	0[Ra]
	Free WA*			+0.6[b]		+0.1[b]		+0.1[b]		- 0.1[b]
	Free no WA			+0.7[b]		±0.0[ab]		+0.1[b]		+0.1[c]
Production system	Conventional	1	0.001	0	0.001	0	0.01	0	0.05	0
	Organic			- 1.4		- 0.9		+0.1		- 0.1
Season	Winter	1	0.001	0	0.001	0	0.001	0	0.001	0
	Summer			- 0.3		- 0.3		±0.0		- 0.1
Breeds	Holstein	1	0.001	0	0.001	0	0.001	0	0.001	0
	Non-holstein			-1.8		- 0.6		±0.0		±0.0
Country	Denmark	1	0.001	0	0.001	0	0.001	±0.0	n.s	0
	Netherlands			-0.9		- 0.6				±0.0
Nr. of robots	(Continuous)	1	0.001	+0.4	n.s	+0.1	0.001	±0.0	0.001	±0.0
Cows served by VMS	(Continuous)	1	0.001	±0.0	0.001	+0.1	0.001	±0.0	0.001	±0.0
Cow fetchings/day	(Continuous)	1	0.001	+0.1	0.001	±0.0	0.001	±0.0	0.001	±0.0
Herd size	(Continuous)	1	0.001	±0.0	0.001	±0.0	0.05	±0.0	n.s	±0.0
Lactation nr*Stage of lactation**	1*1	11	0.001	0	0.001	0	0.001	0	0.001	0
	1*2			+1.9		+0.4		+0.1		+0.1
	1*3			- 0.3		+0.3		±0.0		+0.1
	1*4			- 4.1		- 0.2		±0.0		±0.0
	2*1			+9.8		+2.1		±0.0		+0.2
	2*2			+9.6		+2.7		±0.0		+0.2
	2*3			+4.9		+2.1		- 0.1		+0.2
	2*4			- 1.9		+0.7		±0.0		+0.1
	3*1			+12.0		+3.2		±0.0		+0.2
	3*2			+12.7		+3.7		±0.0		+0.2
	3*3			+6.6		+2.9		- 0.1		+0.2
	3*4			- 1.7		+ 1.0		- 0.0		+0.2

*WA=waiting area

** Stage of lactation grouped into periods 1=0-59, 2=60-119, 3=120-219 and 4=220- days in milking.

[R]Reference level

[abc]Numbers in the same column with the same superscript are not statistically significantly different (p>0.05)

n.s non-significant (p>0.05)

AMS capacity

An ANOVA with the results from the analyses of AMS capacity, including df and level of significance, is presented in Table 8.

Number of cows per robot

Average number of cows per robot was 55.8, 55.8 and 54.1 in Feed First traffic, Free cow traffic with WA and Free cow traffic without WA respectively (Table 6). The differences between number of cows per robot in Feed First and Free cow traffic without WA as well as between Free cow traffic with and without WA were statistically significant ($p<0.001$).

Table 6. *Descriptive statistics, with means and 1st and 3rd quartiles (Qu) for number of cows per robot in different cow traffic systems*

	Feed First	**Free with WA[a]**	**Free without WA**
Mean	55.8	55.8	55.1
1st Qu	49.0	50.7	50.0
3rd Qu	63.0	61.5	61.0

[a]WA=waiting area

Total duration per day

Average total duration of milking per robot and day was 16.6 h, 17.1 h and 16.7 h for Feed First traffic and Free cow traffic with and without WA respectively (Table 7). When the statistical model was considered, total duration per day did not differ significantly between traffic systems (Table 8).

Milk per day

Average total milk yield per robot and day was 1529.8 kg, 1583.7 kg and 1550.6 kg for Feed First traffic and Free cow traffic with and without WA respectively (Table 7). When the statistical model was considered, total milk yield per day did not differ significantly between traffic systems (Table 8).

Number of milkings per day

Average number of milkings per robot and day was 138.1, 142.2 and 140.4 for Feed First traffic and Free cow traffic with and without WA respectively (Table 7). When the results from the statistical model was considered, Feed First traffic resulted in 5.6 fewer visits per robot and day compared to Free cow traffic without WA ($p<0.05$). Total number of milkings per day did not differ significantly between Feed First and Free cow traffic with WA or between Free cow traffic with and without WA (Table 8).

Table 7. Descriptive statistics, with means and 1st and 3rd quartiles (Qu) for robot capacity in different cow traffic systems

Traffic system	**Duration/day (h)**	**Milk/day (kg)**	**Milkings/day**
Feed First			
Mean	16.6	1529.8	138.1
1st Qu	14.9	1251.4	125.0
3rd Qu	18.7	1796.8	153.0
Free WA[a]			
Mean	17.1	1583.7	142.2
1st Qu	15.7	1395.6	130.0
3rd Qu	18.8	1779.0	157.0
Free no WA			
Mean	16.7	1550.6	140.4
1st Qu	15.1	1323.6	127.0
3rd Qu	18.6	1765.9	156.0

*WA=waiting area

Table 8. ANOVA with differences in AMS capacity, as estimated with a multivariable linear regression model, degrees of freedom (df) and level of significance

			Milking duration/day (min)		Milk/day (kg)		Milkings/day	
Fixed factors	**Level**	**df**	**p<**	**Estimate**	**p<**	**Estimate**	**p<**	**Estimate**
Cow traffic	Feed First	2	0.05	0[Ra]	0.001	0[Ra]	0.001	0[Ra]
	Free WA*			+19.8[a]		+34.6[a]		+4.0[ab]
	Free no WA			+16.1[a]		+17.7[a]		+5.6[b]
Production system	Conventional	1	n.s	0	0.01	0	n.s	0
	Organic			- 4.8		- 93.6		+6.1
Season	Fall	1	0.001	0	0.001	0	0.001	0
	Summer			+11.6		+25.6		+2.0
Breeds	Holstein	1	n.s	0	n.s	0	n.s	0
	Non-holstein			-35.9		- 78.8		- 1.6
Country	Denmark	1	0.001	0	0.001	0	0.001	+10.2
	Netherlands			+11.8		- 17.3		
Nr. of robots	(Continuous)	1	0.001	- 14.2	0.001	+23.4	0.001	- 4.0
Cows served by VMS	(Continuous)	1	0.001	+14.9	0.001	+26.0	0.001	+2.0
Cow fetchings/day	(Continuous)	1	0.001	+7.2	0.001	+17.4	n.s	- 0.2
Herd size	(Continuous)	1	0.001	+0.7	0.001	- 0.4	0.001	+0.1
Mean milk flow (0.1 kg/min)	(Continuous)	1	0.001	- 67.1	0.001	+91.6	0.001	- 4.6
(Mean milk flow)^2	(Continuous)	1	0.001	+1.8	0.001	+1.0	0.001	+0.1

[*]WA=waiting area
[R]Reference level
[a]Numbers in the same column with the same superscript are not statistically significantly different (p>0.05)
n.s non-significant (p>0.05)

Farmers' satisfaction

Farmers' satisfaction with the traffic system

The farmers' average grade of their traffic system was 8.1, 8.0 and 7.5 for Feed First, Free cow traffic with WA and Free cow traffic without WA respectively (Table 9). However, the differences were not statistically significant.

Framers' satisfaction with the milking system

The farmers' average grade of their milking system, i.e. the milking system as a whole, including cow traffic, milking unit, barn design etc., was 7.7, 7.6 and 7.7 for Feed First, Free cow traffic with WA and Free cow traffic without WA respectively (Table 9). The differences were not statistically significant.

Table 9. Farmers' average grade of the traffic system

Traffic system	Feed First	Free WA[a]	Free no WA
Average grade traffic system	8.1	8.0	7.5
Average grade milking system*	7.7	7.6	7.7

[a]WA=waiting area

*Milking system = the milking system as a whole, including cow traffic, milking unit, barn design, etc.

Fetching of cows

Number of times fetching cows per VMS and day

In Feed First traffic, farmers reported that they fetched cows on average 1.5 times per day compared to 2.5 in Free cow traffic with WA and 2.3 in Free cow traffic without WA (Table 10). The difference between Feed First and Free cow traffic with WA as well and between Feed First and Free cow traffic without WA was significant ($p>0.001$ and $p>0.05$ respectively). The difference between Free cow traffic with and without WA was however not significant.

Average number of fetched cows per VMS and day

In Feed First traffic, farmers reported that they fetched on average 16.6 cows per day compared to 24.0 in Free cow traffic with WA and 23.0 In Free cow traffic without WA (Table 10). The difference between Feed First and Free cow traffic with WA was significant ($p<0.05$). The difference between Free cow traffic without WA and Feed First or Free cow traffic with WA was however not significant.

Time spent fetching cows per VMS and day

In Feed First traffic, farmers reported that they spent on average 22.8 minutes per day on fetching cows compared to 29.6 in Free cow traffic with WA and 33.2 in Free cow traffic without WA (Table 10). The differences were however not significant.

Table 10. Number of cow fetches, average number of cows fetched and time spent fetching cows (min) per day in different traffic systems

Traffic system	Feed First	Free WA[a]	Free no WA
Number of times fetching cows/day	1.5	2.5	2.3
Average number of fetched cows /day	16.6	24.0	23.0
Time spent fetching cows/day (min)	22.8	29.6	33.2

[*]WA=waiting area

Discussion

In terms of milk production per cow and day and number of milkings per cow and day, Free cow traffic both with and without WA seemed to be more favourable than Feed First traffic. No differences in milk production or number of milkings per day could be established between Free cow traffic with and without WA. In terms of milk conductivity, Free cow traffic with WA showed more favourable results than both Feed First traffic and Free cow traffic without WA while Feed First traffic showed more favourable results than Free cow traffic without WA. The differences were however marginal and it is hard to determine whether or not these results are biologically significant, because using milk conductivity as an indicator for udder health is of most value when comparing results on udder-quarter level or when detecting changes over time. Free cow traffic without WA, resulted in slightly more milkings per robot and day than Feed First traffic, but no other significant differences in AMS capacity could be established between the traffic systems. In Feed First traffic, farmers reported that they fetched cows less often than in Free cow traffic but no statistical difference between number of fetched cows in Free cow traffic with and without WA could be established. Furthermore, farmers with Feed First traffic reported that they fetched fewer cows per day to the milking unit compared to farmers with Free cow traffic with WA. No statistically significant difference between average time spent on fetching cows to the milking unit could be established. Nor could any significant differences between farmers' satisfaction with their traffic system or the milking system be established.

Descriptive data on AMS capacity show that Feed First traffic appears to result in larger variation in milk per robot and day, both representing the highest and the lowest values, than the Free cow traffic systems. Free cow traffic without WA seems to result in smallest variation. This could indicate that Feed First has more potential to reach higher capacity, but that this system also is more complex, resulting in lower capacity if not correctly managed.

Differences in milking intervals due to different type of traffic systems were initially investigated in the study. However the data was not considered reliable, because many observations for this variable were out of range for what was possible, and milking interval was for this reason excluded from the study. Milking intervals could however be estimated based on number of milkings per cow and day. For Feed First traffic, an average of 2.5 milkings per day means an average milking interval of 24 h/2.5 = 9.6 h. Free traffic both with and without WA resulted in + 0.1 milkings per cow and day, compared to Feed First traffic, which subsequently means that the average milking interval for cows in this systems can be estimated to 24 h/2.6 = 9.2 h.

One suggested reason to the results in cow performance could be that farmers with Free cow traffic are aware of the fact that this could result in less visits to the milking unit. Because of this, they have a more optimal management, for example a better feeding strategy, more frequent fetching of cows, better grouping etc., for successful cow traffic, while farmers with Feed First traffic might rely on cows' motivation to eat and rest to ensure frequent milkings. This is also confirmed by the results in our study as well as in the study by Rodenburg and House (2007). Hence, the results might be a consequence of the farmer understanding the system needs rather than a better cow traffic system per se. Although, number of times fetching cows per day was included in the statistical model the accuracy of this information can be questioned since the information was based on rough estimations from the farmers. Furthermore, number of times fetching cows, number of fetched cows and time spent on fetching cows appears to be a bit high. This might be because the farmers misinterpreted the question and reported the total number of fetchings/time spent on fetching instead of the number per VMS. Thus, the mean values for these variables might not be representative for the actual number of fetchings/time spent on fetching. However, since the average number of robots per farm is similar for the different traffic systems the bias should be the same for the different traffic systems and thus, the differences between traffic systems might still be adequate. It should also be mentioned that the variables concerning fetching of cows were not analysed with a multivariable model and thus independent variables that are highly likely to affect the results, such as herd size and number of robots, were not accounted for in the analysis. In a future study, these variables should be analysed with a multivariable model in order to correct for the effect of surrounding factors and thus get more reliable results.

Another explanation to the results could be that Free cow traffic has been commercially available for a longer time than Feed First traffic, and might be overrepresented in farms that have been practicing AMS for a longer time. According to unpublished data from a study by Löf (2013) farms changing from conventional milking to AMS experience a drop in production for up to five years after the implementation of the system. Thus, higher production results in Free cow traffic might be due to the fact that more farms with this system have been practising AMS for a longer time and thus have been able to recover from the dip in production. Although dates for converting to AMS were available in the collected data this was not included in the statistical model. In a future study, this should be considered in the analysis.

One suggested reason to why Free cow traffic seems to be slightly more favourable on the average farm than Feed First traffic in terms of cow performance, except for milk conductivity, could be that this system might be more favourable for low ranked cows. In Free cow traffic, the lower ranked cows can choose to go to the milking unit when there are no cows waiting in front of it. In Feed First traffic on the other hand, the cows are more or less directed to the WA whether or not they intend to. While in the WA, low ranked cows can be pushed away from entering the milking unit by higher ranked cows, resulting in long waiting periods in the WA and therefor longer milking intervals and disturbed time budgets. This is in alignment with the observations that cows standing for long periods can lead to irregular milkings (Harms *et al.*, 2002) as well as inhibited milk let-down response (Winter & Hillerton, 1995) which in turn can lead to impaired milk production.

Even though some significant differences in cow performance between the systems could be established, these were relatively small and the biological significance could be questioned. By increasing milk production by 0.6 kg/cow and day, yield could be increased by approximately 0.6*305 = 210.5 kg per cow and lactation. In a herd with 60 dairy cows, this would mean that milk yield could increase by 12 630 kg per year. Even though this might not sum up to a major amount of money in the end, every coin earned is of value, especially during rough times for dairy farming as it is today when every coin earned is of great value. However, even though milk production per cow is of interest in terms of profitability, in this context, amount of milk per AMS might be of even higher value. Even though a low number of cows per AMS might result in high production per cow, it will however also result in low milk per AMS which is unfavourable in terms of achieving maximum return on the investment done on the AMS. According to this study, no significant differences in milk per AMS could be established. Also, one of the main advantages with AMS is the reduced labour and thus reduced labour costs. However, in order to achieve this, cows have to visit the milking station voluntarily so that minimum time is spent on fetching cows. This study showed no significant differences in time spent on fetching cows to the AMS, even though the data could be questioned as discussed earlier. If, however, the differences do represent the actual number of fetcings in the different traffic systems, Feed First traffic required 6.8-10.4 less minutes per day fetching cows compared to Free cow traffic with and without WA. Subsequently, this means a difference of 41.4- 63.3 h per year which in some ways could compensate for the lower production per cow, especially since higher production might not always be desirable since this could lead to health problems as well as higher feed costs.

The fact that the study failed to establish any larger differences in cow performance and AMS capacity might be explained by two facts. Either, the data was not valid enough to prove larger or existing differences or there were no major differences between the traffic systems. Even though the dataset included many observations, there might not have been enough farms representing the different traffic solutions. Since we contacted all farms with Feed First traffic in both countries, farms from one or several more countries would have to be included in order to expand the number of farms with Feed First traffic. Even though the majority of the farmers agreed to participate, many did not return the memory stick which resulted in a lower number of participating farms than expected. One reason for this might be because the study was performed during a busy period from a farmers' point of view. In order to ensure a higher participant frequency, the data could be collected during another time of the year, when farmers are not as busy with crop production.

Further, the quality of some of the gathered data can be questioned. Interviews might not be an optimal way of collecting data because of the risk for misinterpretation. Moreover, there are several modifications of the same traffic system which might have different impact on cow traffic. For example, many of the farms with Feed First traffic had a so called 3+0 barn layout. This means that there is a row with cubicles in the same area as the feeding area and thus, this system cannot be equalized with a pure Feed First system where the cows can stay in the feeding area, because they can lay down and eat in the same area without passing the selection gate. In a future study, all different traffic solutions should be discussed and straighten out thoroughly with interviewers and representatives from DeLaval from all countries. This also includes different versions/modifications of the same traffic system. In order to make sure that the traffic system is identified correctly, the traffic should be investigated more thoroughly on each farm, preferably by farm visits. If farm visits could be arranged and the interviews could be done on the farm, the interviewer could get a better understanding of the farms system and management. Further, the copying of the data could be done by the interviewer during the visit which could solve the problem with farmers not returning the memory sticks.

Another reason why the data might not have been sufficient enough to establish any larger differences can be that cow traffic is affected by so many factors and since every farm is unique these differences could not be embraced in the statistical model. For example, different feeding regimes, which are extremely important for the success of cow traffic, were not considered in the analysis. Perhaps, if the effect "pure" of different traffic systems on production performance should be investigated, more significant and larger differences can be achieved if the study is done on one herd under different traffic conditions but same management conditions. However, in order to investigate which on-farm factors that are of importance for a successful production in different traffic solutions, also further studies done under different management conditions are of importance.

The fact that the traffic is affected by so many surrounding factors might also be an explanation to why the type of traffic system might not have a major impact on cow performance or AMS capacity. Maybe, the traffic system is not as important for the cow traffic as other management and farm-level factors such as feeding routines and hoof health. This does however contradict the statement by Forsberg (2008) that the traffic system seems to be a key factor for successful management of cows housed an AMS. It is, on the other hand, confirmed by the study by Jacobs & Siegford (2012b) as well as by the contradictory results of the previous studies done on cow traffic. The success of cow traffic in an AMS is dependent on a very complex interaction between different factors concerning management, barn layout, health status etc. Hence, a good traffic could be accomplished in a, as it appears, "non-optimal" traffic solution but with good management. Thus, the success of the cow traffic can be used as an indicator of the herd status, i.e. if the management and health status is good, cow traffic will be successful. However, more research is needed within this area in order to further investigate the question and confirm the results in this study.

It should also be mentioned that the articles reviewed in this study should be regarded with caution. Many of the older studies may be obsolete and out of date (Jacobs & Siegford, 2012a), because AMS and cow traffic systems are relatively new features in dairy production and management routines for optimal traffic and system capacity are still under development. Furthermore, since the access to studies concerning this topic is limited, many of the references used in the literature review are from conferences and not reviewed articles. This supports the conclusion that more up to date research is needed within this area.

This study is an important first and unique step in starting to understand the traffic systems in practice as well as getting descriptive data on the field data regarding cow performance and VMS capacity from VMS herds in Denmark and the Netherlands. The data will be of high value in future studies further investigating for example which factors, more in detail, that are of importance for the cow traffic in the different traffic solutions. The results from the study will provide a tool for counselling dairy farmers in their choice between different traffic solutions. For DeLavals customers and for the sake of VMS sales it is important to find solid proof and knowledge of all major economical differences between some of the most prevalent cow traffic systems Free traffic with and without WA and Feed First and to suggest solutions for any known or new disadvantage of the systems.

Conclusions

Farmers with Feed First traffic reported that they fetched cows less often than farmers with Free cow traffic did. No significant differences in time spent fetching cows to the milking unit or farmers' satisfaction between the traffic systems could be established. In terms of AMS capacity, Free cow traffic without WA, resulted in slightly more milkings per robot and day than Feed First traffic but no other significant differences in AMS capacity could be established between traffic systems. In terms of cow performance, except milk conductivity, Free cow traffic both with and without WA seems to be more favourable than Feed First traffic. Whether the differences are due to actual differences in traffic systems or management is hard to determine. Several management factors, such as feeding strategy, may determine the success of cow traffic. These factors might be more important in order to obtain successful cow traffic, than the type of traffic system. More research, taking these factors into account, is needed to investigate the question further and to confirm the results in this study.

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