Behaviour and throughput of dairy cows when entering and exiting two types of parallel rotaries

Mjölkkors beteende och genomflöde under på- och avstigning i två typer av bås i roterande parallellstall

Julia Andersson

Skara 2014

Husdjursagronomprogrammet


Studentarbete **Nr. 528**
Sveriges lantbruksuniversitet
Institutionen för husdjurens miljö och hälsa

Student report ***No. 528***
Swedish University of Agricultural Sciences
Department of Animal Environment and Health

ISSN 1652-280X

Behaviour and throughput of dairy cows when entering and exiting two types of parallel rotaries

Mjölkkors beteende och genomflöde under på- och avstigning i två typer av bås i roterande parallellstall

Julia Andersson

Studentarbete 528, Skara 2014

Avancerad nivå AE2, 45 Hp, Husdjursagronomprogrammet,
Degree Project in Animal Science, EX0719

Handledare: Lena Lidfors, Inst. för husdjurens miljö och hälsa,
Box 234, Gråbrödragatan 19, 532 23 Skara
Biträdande handledare: Klaus Aye, Business Manager CMS Rotary Systems DeLaval,
DeLaval International AB, Gustaf de Lavals väg 15, 147 21 Tumba, Sweden
Biträdande handledare: Charlotte Hallén-Sandgren, Dairy Development Director DeLaval,
DeLaval International AB, Gustaf de Lavals väg 15, 147 21 Tumba, Sweden
Examinator: Lotta Berg, Inst. för husdjurens miljö och hälsa,
Box 234, Gråbrödragatan 19, 532 23 Skara

Nyckelord: dairy cow, parallel rotary, throughput, cow behaviour

Serie: Studentarbete/Sveriges lantbruksuniversitet, Institutionen för husdjurens miljö och hälsa, nr. 528, ISSN 1652-280X

Sveriges lantbruksuniversitet
Fakulteten för veterinärmedicin och husdjursvetenskap
Institutionen för husdjurens miljö och hälsa
Box 234, 532 23 SKARA
E-post: hmh@slu.se, **Hemsida:** www.slu.se/husdjurmiljohalsa

I denna serie publiceras olika typer av studentarbeten, bl.a. examensarbeten, vanligtvis omfattande 7,5-30 hp. Studentarbeten ingår som en obligatorisk del i olika program och syftar till att under handledning ge den studerande träning i att självständigt och på ett vetenskapligt sätt lösa en uppgift. Arbetenas innehåll, resultat och slutsatser bör således bedömas mot denna bakgrund.

Table of content

1. Summary

Today a trend can be seen towards fewer dairy farms and increasing number of cows per farm. Larger farms set a higher demand of more labour efficient milking systems. The time to enter and exit milking rotary platforms is crucial to maintain a high cow throughput. This study is a project initiated by DeLaval in order to evaluate the cow throughput and cow behaviour during entry and exit in two types of parallel external rotaries with different bail designs. The two rotaries compared were DeLaval parallel rotary PR2100 and PR3100HD. The study included nine different farms located in Sweden, Denmark and Germany.

The cow throughput was significantly higher in the PR3100HD with 277.7 cows per h compared to the PR2100 with 196.9 cows per h. The individual cow exit time was significantly shorter in the PR3100HD with 13.3 s compared to 19.8 s in the PR2100. No significant difference could be found for cow entry time between the two rotary models and the average entry time was 5.1-5.4 s. When feeding in the rotary and cow locator in the bail was investigated these factors had no significant effect on cow entry time. In the PR3100HD the cows were pushed by other cows significantly more during entry compared to in the PR2100. The cows were backing into other cows significantly more and showed a tendency of standing still more at the exit in the PR2100, causing problems for the cow throughput. Other observed behaviours during entry and exit were not significantly different between the two rotary models. Direct observations indicated that the cow throughput could be improved by further development and adaptation of the layout in exit area and exit lane.

1. Sammanfattning

I dag finns en trend mot allt färre gårdar med ett ökande antal kor per gård vilket ställer högre krav på mer effektiva mjölkningssystem. För att upprätthålla ett högt flöde av kor i mjölkningskaruseller är på- och avstigningstiden till plattformen avgörande. Den här studien är ett projekt på uppdrag av DeLaval för att utvärdera mjölkkors beteende och genomflöde under på- och avstigning i roterande parallellstall med två typer av bås. De två parallellstallen som jämfördes var DeLavals roterande parallellstall PR2100 och PR3100HD. Studien inkluderade nio olika gårdar lokaliserade i Sverige, Danmark och Tyskland.

Genomflödet av kor var signifikant högre i PR3100HD med 277.7 kor per h jämfört med 196.9 kor per h i PR2100. Kornas individuella avstigningstid var signifikant snabbare i PR3100HD med 13.3 s jämfört med 19.8 s i PR2100. Det fanns ingen signifikant skillnad för kornas påstigningstid mellan de två olika modellerna och den genomsnittliga tiden var 5.1-5.4 s. Utfodring i karusellen och ”cow locator” i båset hade ingen signifikant effekt på kornas påstigningstid. I PR3100HD blev korna signifikant mer knuffade av andra kor under påstigningen jämfört med i PR2100. Korna backade på varandra signifikant mer och visade en tendens till att stå stilla mer i PR2100 vilket orsakar potentiella problem för kotrafiken. Andra beteenden som observerades under på- och avstigningen i karusellen visade ingen signifikant skillnad mellan de två karusellmodellerna. Direktobservationer visade att genomflödet av kor kan förbättras genom att utveckla och anpassa layouten bättre vid avstigningen från plattformen och transportgången som leder därifrån.

2. Introduction

Today a trend can be seen towards fewer dairy farms and increasing number of cows per farm (SJV, 2013). This trend can be seen both in countries in EU and other parts of the world (Thomas et al., 1996). Increasing number of cows per farm sets a higher demand of more labour efficient milking systems because milking represents the single largest time consuming task of hired labour on a dairy farm (O'Donovan et al., 2008; Taylor et al., 2009). In order to reduce the farm expense it is important to maintain efficient milking routines in terms of high cow throughput. The time to enter and exit milking rotary platforms is crucial to the throughput of cows and the amount of milk which can be harvested per hour. This study is a project initiated by DeLaval in order to evaluate the efficiency, cow throughput and cow behaviour in two parallel external rotaries with different bail designs.

3. Literature review

3.1 Dairy cow behaviours related to milking

In parlour milking systems dairy cows are standing close together in a waiting area before they enter the milking parlour (Ishiwata et al., 2005). During this time the cows are restricted from keeping individual distances, perform natural behaviours as feeding and are not able to lie down (Ishiwata et al., 2005; Dijkstra et al., 2012). Cows often have to wait for long periods before they enter the milking parlour standing in the waiting area for up to 2 h per session. In a behavioural study in the waiting area it was found that on average 30-50 % of the cows ruminated (Dijkstra et al., 2012). Rumination also increased during the milking procedure. The highest frequency of rumination was observed where cows had the shortest waiting time and biggest space per cow in the waiting area. However it was not possible to tell if the cows started to ruminate more during the time or if some cows ruminated for a longer period and remained among the last cows. Other behaviours in the waiting area seem to be poorly expressed. Records on aggression, self-grooming, allogrooming, mounting and vocalization all occurred below 2 % among the cows (Dijkstra et al., 2012). Another study focused on cows that raised their heads in the waiting area, referred to as "looking up" behaviour which occurred between 9-26 % (Ishiwata et al., 2005). The cows that performed the "looking up" behaviour more often in the waiting area were younger cows with lower milk production and less experience of being milked. These cows were also more sensitive to flight response when approached by humans and entered the milking parlour later (Ishiwata et al., 2005).

It is important to implement a good milking routine from the beginning because dairy cows are well known to be affected by the milking staff. When comparing different handling methods the cows kept a longer distance to a more aversive handler compared to a gentle handler (Rushen et al., 1999; Munksgaard et al., 2001). By observing neighbours receiving a gentle treatment the cows learned to keep a closer distance to the same person (Munksgaard et al., 2001). Training of heifers could be important because the milking procedure has shown to be stressful to some heifers during the beginning of lactation resulting in inhibited milk ejection the first days (Van Reenen et al., 2002). When examining the effect of trained heifers in the milking parlour before calving Sutherland and Huddart (2012) found that training can reduce the stress in the beginning of lactation. During the first week of lactation trained heifers had lower residual milk volumes, higher milk flow rates and shorter milking durations. Depending on animal temperament training of heifers can reduce the avoidance distance to humans (Sutherland & Huddart, 2012). Avoidance distance could also be dependent on breed.

Dodzi and Muchenje (2011) found that Friesland cows seemed to be more fearful than Jersey cows when comparing avoidance distance.

Dodzi and Muchenje (2011) observed cow entry behaviour and exit pace in a milking parlour for Friesland, Jersey and crossbred cows. The percentage of cows stopping before entry at the platform varied between 20-40 % where Jersey presented the lowest frequency. When the cows exit the rotary it was recorded if they were walking, trotting or running. A difference between the breeds were found where about 80 % of the Jerseys walked away, 70 % of the Friesland trotted away and below 10 % were running away (Dodzi & Muchenje, 2011).

3.2 Entrance order

When studying cow entrance order in milking parlours, grouping as well as health status, could be important (Phillips & Rind 2002; Main et al., 2010). It has been observed that lame cows tend to enter the milking parlour toward the end of the milking (Main et al., 2010). Cows that tend to enter the milking parlour early are more dominant and dominance is related to body weight, lactation number and milk production (Phillips & Rind, 2002).

Consistency of the milking order of dairy cows has been demonstrated in several studies. According to Rathore (1982) cows with higher milk yield came earlier to milking and lower yielding cows appeared towards the end of the milking. This result is supported by later studies also concluding that higher yielding cows enter the milking parlour first (Phillips & Rind, 2002; Grasso et al., 2007; Berry & McCarthy, 2012). However Grasso et al. (2007) only confirmed a significant correlation between entrance order and milk yield for primiparous cows even if multiparous cows showed a consistent order. The influence of dominance on milking order has also been confirmed in automatic milking systems (AMS) where cows of high rank spent shorter time in the waiting area to the milking unit compared to low ranked cows (Ketelaar-deLauwere et al., 1996; Melin et al., 2006). Phillips and Rind (2002) also found that entry orders for morning and evening milking were positively correlated. Furthermore cows entering early have been observed to have lower somatic cell count compared to the cows entering at a later stage (Rathore, 1982; Berry & McCarthy, 2012).

3.3 Feeding

Overall the motivation for a cow to be milked may be weak (Prescott et al., 1998; Melin et al., 2006) and highly variable between cows (Prescott et al., 1998). Some studies have described how access to feed can be used as a motivator for cows being milked (Prescott et al., 1998; Melin et al., 2006; Kolbach et al., 2013). Even if milking itself act as a reward for the cow access to feed had a higher priority (Prescott et al., 1998; Melin et al., 2006).

When examining the effect of feeding in a robotic rotary the proportion of available bails that were occupied by cows was significantly higher when the cows were fed (Kolbach et al., 2013). Feeding in the rotary resulted in 90% utilized bails compared to only 59 % with no feeding. When feed was available it was 5.7 times more likely that the bail was utilized, consequently cow traffic onto the platform was improved by feeding. It was concluded that delays related to cow traffic can be avoided with feeding since it contributes to voluntary cow entry (Kolbach et al., 2013).

3.4 Milking parlour efficiency and cow throughput

A high cow throughput during milking is of interest in order to reduce the time for the cows standing in the waiting area as opposed to lying and ruminating (Österman & Redbo, 2001) which can improve both productivity (Rushen & de Passillé, 1999) and health status (Galindo & Broom, 2000). Increased time spent standing leads to increased incidents of lameness (Galindo & Broom, 2000). The overall milking efficiency and parlour performance is influenced by many factors. Some of the most important factors include the number of milking units, operator work routine, individual cow production and duration of milking cluster attachment to the cow. The total herd milking time can be reduced by increasing the number of milking units as long as labour not is limiting. The required labour is dependent on work routines and automated tasks (O´Brien et al., 2012).

In New Zeeland cow throughput and labour efficiency were examined in rotaries ranging from 28 to 80 bails at 61 pasture-based farms. With increasing rotary size number of cows milked and amount of milk harvested per hour increased linearly (Edwards et al., 2013). This is in line with Nitzan et al. (2006) who also found that cow throughput increased linearly with increasing rotary size from 10 to 40 bails. Edwards et al. (2013) also found that most of the farms with 60 bails or fewer were operated by one person while many farms with more than 60 bails were operated by more than one person. Operator efficiency, measured per operator h for cows and kg milk respectively, turned out to peak at a rotary size of ~60 bails. These results conclude that larger rotaries (>60 bails) have a higher potential cow throughput but are not more labour efficient than medium sized rotaries (40-60 bails). The potential throughput can however be limited by individual conditions and operational practices (Edwards et al., 2013). As long as the working routine drives the operator towards the limiting point there is no efficiency gain by installing larger parlours (O´Brien et al., 2012).

It has been investigated how cow throughput is influenced by different platform speeds in dairy rotaries. When increasing the platform speed the percentage of “go-around” cows, e.g. the number of cows that required a second rotation, increased together with cow throughput and bail utilization (Nitzan et al., 2006; Edwards et al., 2012). The highest potential throughput was achieved in an 80 bail rotary with 484 cows per h and a speed of 5 s per bail. However the potential throughput is limited when the amount of “go-around” cows is taken into consideration. The throughput was calculated to be highest at ~20 % “go-around” cows (Edwards et al., 2012). Faster rotary speed leads to shorter total milking times (Nitzan et al., 2006). Decreasing the rotation time from 10 min per rotary lap to 8 min can result in a saving of 8.6 min per milking. The possibility of using higher rotary speed is dependent on good cow flow during platform entry and exit together with milking goals at the farm. When a farm use feeding in the rotary for example, a slower rotary speed could be more sufficient in order to allow the cows to finish. Consequences of increasing platform speed could be increased maintenance cost or requirement of additional operators leading to increased labour input. The authors suggest that the platform speed should be set based on operator ability rather than the amount of “go-around” cows. It is also proposed that larger rotaries need to be set at higher speed compared to smaller rotaries in order to compensate for higher investment cost (Edwards et al., 2012). When planning for large milking parlours it has to be taken in consideration that management influence the parlour and labour efficiency (Smith et al., 1998).

Smith et al. (1998) conducted a study on milking parlour performance in four types of milking parlours measuring cow throughput. Three rotaries were included in the study that consisted of 22, 40 and 48 bails run by 1-3 operators and had a steady-state cow throughput at 92, 203 and 192 cows/h respectively. The 48 bail rotary was the only one implementing a full pre-milking hygiene including strip, pre-dip, wipe and attach milking units which require more time per cow compared to only strip or wipe and attach. The extra time required for a full pre-milking preparation could be compensated by adding more operators in order to maintain high cow throughput and udder health at the same time (Smith et al., 1998).

4. Aim and questions

The aim of this study was to compare the behaviour and throughput of dairy cows during entry and exit of external milking rotary platforms with different bail designs. To be able to compare the throughput time of the two bail designs possible causes that can affect the throughput during and between milking sessions was recorded. The two types of cow bails that were compared was DeLaval parallel rotary PR2100 and DeLaval parallel rotary PR3100HD. The PR2100 has parallel cow bails with the cows standing in a 90 degree angle towards the platform outer edge while the PR3100HD has 15 degree angled bails with the cows standing in a 75 degree angle towards the platform outer edge.

This study only involves farms that have invested in the parallel rotary PR2100 or PR3100HD from DeLaval in recent years. Because of time and cost aspect this study is limited to farms in Europe, e.g. Sweden, Denmark and Germany.

The following questions were investigated:

- Are there any differences in entry and exit times between the two rotary designs?
- What is the average cow throughput and are there any differences between the two systems compared?
- Are there any differences in cow behaviours during entry and exit between the two rotary designs?
- If there are differences between the two rotary designs what could be the reasons?

4.1 Hypothesis

The hypothesis was that the parallel rotary PR3100HD is more beneficial for the throughput of cows because the angle is believed to give the possibility for the cows to back off and turn around earlier at the exit. The angled bail was also believed to give a faster entry to the platform because the cows do not walk straight towards the front rail in the bail and are able to catch up on the moving bail.

5. Materials and methods

The data collection was performed between August 26 and October 10 during 2013 and included nine farms.

5.1 Farms and rotaries

Three of the farms were located in Sweden, two in Denmark and four in Germany. Five farms had the parallel rotary PR2100 and four farms had the parallel rotary PR3100HD (Figure 1 and 2). The nine farms were named A-I in a random order between all three countries. The farms A-E had the parallel rotary PR2100 while the farms F-I had the PR3100HD (Table 1).

The PR2100 was available in all three countries while the PR3100HD was available in two of the countries.

Figure 1. Photos of the entry in the PR2100 (A) and the PR3100HD (B).

Figure 2. Photos of the exit area in the PR2100 (A) and PR3100HD (B).

The installation year of the rotary varied between 2009 and 2013 (Table 1). The two most recent farms that invested in the rotary during 2013 started to milk their cows in the rotary during May and July respectively. At the time of the data collection all farms had been milking at least three months in the rotary. All farms with the PR2100 had one cow entry lane where the cows in the entry lane were walking one cow after each other to the rotary (Figure 1A). All the farms with the PR3100HD had a 1.5 cow entry lane that was wider, allowing cows to pass each other before they entered the platform (Figure 1B). On all farms a herding gate was used and the cows could enter the rotary in one bail at a time and back off the rotary platform from three bails at the exit. All the farms with the PR3100HD had an exit bow behind the first bail at the exit area. The exit bow is a shaped metal rail that provides space for one cow to back off the rotary platform onto the flooring area surrounded by the rail, before the cow turns around (Figure 3A).

Figure 3. Photo of the exit bow at the exit area in the PR3100HD (A) and the cow locator in the bail between the cow´s rear legs (B).

The total number of bails in the rotaries varied between 44 and 72 (Table 1). Five of the farms turned their rotary in right direction and four farms used left direction. Both right and left direction of rotation was represented in the two rotary models. Feeding of concentrate is only possible in the PR2100 where three farms fed their cows in the rotary and two did not (Table 1). Four of the farms had also invested in a teat spraying robot (TSR) placed some bails before the exit, but it was only installed at three farms during the visit. All farms with the teat spraying robot also had a plate called cow locator in the bail (Figure 3B) to help the TSR reach the udder (Table 1).

Table 1. Rotary information about the farms A-I including rotary model (PR2100/PR3100HD), installation year of the rotary, number of bails in the rotary, if the farm had feeding of concentrate in the rotary and if the farm had the cow locator

Farm	Rotary	Installation year	No. bail	Feed	Cow locator
A	PR2100	2013	60	No	Yes
B	PR2100	2012	50	Yes	No
C	PR2100	2012	44	Yes	Yes
D	PR2100	2009	60	No	No
E	PR2100	2010	50	Yes	No
F	PR3100HD	2011	60	No	Yes
G	PR3100HD	2012	60	No	No
H	PR3100HD	2013	60	No	Yes
I	PR3100HD	2012	72	No	No

Seven farms used different back off devices and in different combination, whereas farm C and E did not use any back off device in the rotary. The back off devices was placed in front or above the three bails where the cows had access to back off the rotary. The different back off devices included rubber mats, plastic barrels, chains, metal parts and water. Only one farm used constant water spray and it was placed above the last bail the cows could exit. At farm B and H electricity was constantly used in chains during the milking session, but at farm B the cows had the possibility to duck under the chains and take a second turn in the rotary. Farm I had the possibility to turn on electricity in the rubber mat with conductors and farm A and C had trained the cows with electricity at the start up. Use of electricity was arranged by the individual farms and is not provided or encouraged by DeLaval. Three of the farms milked some of the cows in an alternative milking system to the rotary. Bucket milking of individual cows was possible in all rotaries. More details for each farm are shown in Appendix 1.

All of the animals were kept in free stall systems and brought to and from the rotary in lanes between the different groups of cows. The lanes used for transportation of cows mainly consisted of slatted concrete flooring. The flooring in the housing groups differed between the farms and consisted of slatted concrete, solid concrete, slatted rubber or asphalt.

Different flooring materials were also used at different places around the rotary. The flooring in the waiting area consisted of concrete, slatted concrete, rubber or slatted rubber. Concrete was the most common flooring at the entry area while rubber was most common on the rotary platform and at the exit area. After the exit area in the exit lane slatted concrete flooring was most common (Appendix 2).

To get back to the housing groups the cows had to walk between 20-200 m. The transition from exit area to exit lane was variable between the farms in length, angle and width. After the rotary exit the farms could have a claw bath, selection gates and/or corners in the exit lane. Two of the farms were not using claw bath after milking in the rotary. At the other farms the frequency of using claw bath after milking differed between the farms from once per two weeks to seven times per week. At some farms the claw bath was permanently placed in the exit lane with or without water in it. At other farms the cows had to take a different route in the exit lane to pass the claw bath. The distance to the claw bath after the rotary varied from 7 to above 42 m. The selection gate was placed from 8 to 42 m from the rotary exit and the distance to the first 90° corner and less angled corners varied from 3.5 to 35 m. The most common width of the exit lane was 80-90 cm (Appendix 2).

5.2 Animals and milking

At seven of the nine farms Holstein was the dominating breed representing 75-99 %. At the other two farms Nordic red was the dominating breed representing 60-70 % of the cows. Other breeds at the farms were Red Holstein, Jersey and Simmental which represented maximum 5 % of the animals per farm.

The number of lactating cows at the farms varied between 300 and 1 300 while the number of lactating cow groups varied between two and 16 (Table 2). Five farms milked the cows twice per day and four farms milked the cows three times per day (Table 2). The morning milking session begun between 4.00 and 8.00 o´clock while the evening milking begun between 16.00 and 22.00 (Table 2). The farms that also had midday milking started between 12.00 and 14.00 (Table 2). The whole milking session varied between two and eight hours at the different farms (Table 2).

In the PR2100 there were two to three operators and in the RP3100HD there were three to four operators. The first person was preparing the udders, the second was attaching the milking clusters while the third person collected and herded the cows to and from the rotary and cleaned the cubicles in the housing groups. At the farms where no TSR was available the second or third person was also responsible for post dipping or spraying the teats when the cows had finished milking in the rotary. At the farms with four persons the extra person could be altering between herding cows and milking in the rotary with the other operators. At one farm (E) it was only two persons involved in the milking. At that farm one person attached the clusters while the other one collected the cows and post sprayed the teats. Energy corrected milk (ECM) per cow and year varied from 8 350 to 10 700 between the farms (Table 2). During the farm visit the cows were milking on average 9-14 kg per cow in the PR2100 and 9-12 kg per cow in the PR3100HD. For detailed information about milking groups at each farm see Appendix 3 and 4.

Table 2. Milking information for all farms including number of lactating cows, number of lactating cow groups, number of milking times/day, time when the milking shifts started in the morning, midday and evening respectively, the duration for each milking shift (hours), and the energy corrected milk (ECM) per cow and year

Farm	Cows	Groups	Milking	Morning	Midday	Evening	Duration	ECM
A	370	2	2	4.00	No	16.00	3	10 378
B	300	3	3	5.00	13.00	21.00	2	9 800
C	480	4	3	5.00	13.00	21.00	3	9 500
D	1080	7	2	5.00	No	17.00	5-6	8 350
E	300	6	2	6.30	No	17.00	2,5	9 500
F	1160	16	2	8.00	No	20.00	8	10 500
G	960	4	3	4.30	14.00	22.00	4	10 600
H	1000	12	2	4.00	No	16.00	8	10 700
I	1300	7	3	4.00	12.00	19.30	5-6	9 300

5.3 Study design

All three countries were visited after each other and the order of the rotary models was mixed. At each farm six milking sessions were recorded with four surveillance cameras (AVTECH, Taiwan) to cover different angles of the rotary. Two of the cameras were positioned above the entry and two were positioned above the exit. In order to direct all the cameras they were connected to a mini-monitor that showed the pictures of the cameras. Each video camera was connected to a DVR-unit (AVC792C, AVTECH, Taiwan) with a cable. The DVR-unit stored all the recorded data that was transferred to two external hard drives for further storage.

The cameras were attached to one wooden plank each and then mounted in the rails above the rotary and cables were led along the rails to the DVR-unit. The DVR was placed as far away from the rotary as possible on a shelf or in a computer room to protect the electrical equipment from water and animals. The cables were 20 to 30 m long. On the first day at each farm the cameras and DVR were positioned and the recordings started at the midday or evening milking the same day. On the farms with two milking sessions (A, D, E, F, H) three morning and three evening sessions were recorded. On the farms that milked three times per day (B, C, G, I) three morning and three midday sessions were recorded.

5.4 Behavioural recording

The behavioural recording for each farm included 12 video sessions per farm from the six recorded milking sessions and were equally distributed between morning and midday or evening milking as well as between entry and exit to the rotary. Each selected video session was randomized between time of the milking shift and between all recorded days. In order to get average representative observations for each farm the first five cows and the last ten cows in a milking group were excluded. Group changes were avoided but if they occurred during the observation period the observation time was paused before the last ten cows and started again after five cows in the next group.

Some milking groups were also excluded from the video analysis. These groups included cows that were newly calved, sick, lame, grouped for culling, treatment, mastitis, dry or in a mixed group with some of these categories. This was made in order to capture the steady-state cow throughput and present a more representative value for each farm. At farms with few cow groups some of the cows were not grouped separately and hence not possible to exclude to 100 %. At farm E all the milking groups were mixed in the waiting area and it was not possible to distinguish between the groups during video analysis. For a detailed list on recorded cow behaviours see Table 3.

Table 3. Recorded cow behaviours at entry and exit and their definition

Behaviour	**Definition**
Voluntary	The cow enters the rotary without any interference from another cow/human/tool
Ruminate	The cow makes chewing movement with the cheeks or regurgitating food bolus
Sniff	The cow stretch her neck forward and is in physical contact with another cow/human/housing with the tongue inside her mouth
Pushed*	Another cow press her head with constant force at the udder/leg/side of the observed cow
Pushed**	Another cow press the rear part of the body at the front part/side of the observed cow
Head push*	Two cows pushes their heads against each other
Bump**	The cow press the rear part of the body against another cow/housing
Stand**	The cow stops and stand still with all four hooves touching the ground
Rub	The head or side of the body is moved up and down repeatedly against another cow/housing
Scratch	The cow use a hoof to scratch herself on the body
Lick	The cow has her tongue outside the mouth and within 5 cm from another cow/human/fittings
Lick self	The cow moves her tongue repeatedly in contact with her body
Throw head**	The cow turn her head to reach the back or side of the body repeated times with the tongue inside her mouth
Chin rest	The cow has her chin on the back of another cow
Mounting attempts	The cow puts her head on the back of another cow and the front hooves are lifted from the ground
Mounting	The cow puts her front legs and chest on another cows back with only the rear legs touching the ground
Eliminate	The cow arches her back and urination or faeces leave the body
Kick	The cow raise her rear hoof up at least to the height of the udder before it is quickly and with force pushed away
Slip	At least one hoof is quickly moved while still in contact with the floor
Kneel	At least one knee of the cow touches the floor
Fall	The body of the cow suddenly moves downwards so the stomach touches the floor
Lie down	The cow lowers her front body and kneels thereafter she lowers the hind part until the stomach touches the ground
Limp	The cow avoids to put weight on one hoof while standing and walking

*Only entry
**Only exit

It was also recorded at entry and exit if there were empty bails in the rotary, if there were cows that took a second rotary lap, if the rotary was run backwards and if the staff were herding the cows in the exit area or exit lane.

During the behavioural recording the number of stops in the rotary and stop duration were also included along with possible causes of rotary stop and if the staff influenced the cows during entry or exit. The reasons for rotary stops were divided between problems with cow traffic and other reasons. Problem with cow traffic was recorded if the staff stopped the rotary because a cow did not enter/exit or if a cow caused a stop by bumping into the safety switch because it did not enter/exit. The rotary stop duration was measured as below 30 s, between 31 to 60 s or above 60 s. Factors that were recorded for staff influence during entry or exit involved if the staff used any kind of the following tools to make the cow enter: towel, stick/scrape or water spray. It was also recorded if the staff used the hand to make the cow enter by waving or touching the cow from the milking position on the floor, from beside the cow or by walking behind the cow in the entry lane.

5.4.1 Cow throughput

During each of the 12 video sessions of behavioural recordings a total number of 60 cows passed. The duration for all 12 groups per farm was recorded in order to measure the cow throughput including rotary stops. The average time for the 60 cows was converted to cows per h for each farm and rotary model.

5.4.2 Entry

During each of the 12 observation periods where 60 cows entered the individual cow´s entry time was recorded for every second cow. This resulted in 30 recorded cows per observation period and gives in total (30*12) 360 observed cows per farm at the entry.

The entry time for an individual cow started when the cow made the final movement towards the rotary that ended on the platform. The entry time stopped when the cow had placed all four claws on the rotary and made no further movement forward. The behaviours that the cow performed directly before the movement forward until she had entered the rotary were recorded.

5.4.3 Exit

During each of the 12 observation periods where 60 cows exited the individual cow´s exit time was recorded for every third cow. This resulted in 20 recorded cows per observation period and gives in total (20*12) 240 observed cows per farm at the exit. The reason why every third cow was observed was because three cows can exit from the three bails at the same time.

The exit time started when the cow made a movement backwards and lifted the first claw off the rotary platform. If the cow was pushing backwards against the rail before she had access to back off the rotary this time was not included in the measure. The exit time stopped when the cow had backed off the rotary platform with all claws and turned around at least 90°. No cow was observed for longer than 60 s even if the cow had not turned around during that period. The behaviours that the cow expressed during the measured exit time were recorded. It was not possible to follow the cow´s behaviour any further due to the continuous flow of new cows.

5.5 Direct observation

During each of the six video recordings a direct observation was carried out to record information about the milking procedure that could not be covered by the cameras. Every direct observation consisted of two hours each and thus covers in total six hours during morning milking and six hours during midday or evening milking per farm. During one of the two hours the cows at the entry were observed and during the other hour the cows at exit was observed. It was randomized if the observation started at the entry or exit. The direct observation was arranged to cover different hours of the milking session every time. For each direct observation it was randomized for which hours of the milking session that should be observed. All observations were recorded into a digital audio recorder and files were saved on a computer. For behaviours the same definitions as for the video analysis were used (Table 3).

5.6 Milking data

At each farm data backup files on milking data were collected from DeLaval ALPRO™ and DeLaval DelPro™ management program for the days the video recordings were performed. All farms except farm F used the ALPRO™ program. Milking performance was created on milking group level at all farms including number of lactations, total milk yield, average milk duration seven days for all milking sessions per day and average days in milk (DIM). The numbers are mean values from the three days of video recordings. The seven day average milk duration includes the days for the farm visit. All milking group categories are based on personal information from farmers. Milk yield and milk duration are not presented for groups where bucket milking was used for the majority of the cows due to lack of milking data for these cows. Milk yield and milk duration is not automatically registered when the milk is collected in buckets instead of in the milking clusters on the rotary.

Rotary performance in ALPRO™ and DelPro™ was created on milk session level measuring number of cows milked per h during all milking sessions for three days. The whole milking sessions were included for cows per h and thereby cover all milking groups containing lame cows etc. Cows per hour in ALPRO™ and DelPro™ is measured from when the first cow enter the rotary until the last cow exit the rotary, and does not include preparation time and cleaning time in the rotary before and after the cows were milked.

5.7 Data analysis

The program Statistical Analysis Software (SAS, Cary, USA) version 9.3 was used to analyse the raw data collected from the 24 behavioural observation periods per farm, ALPRO™ and DelPro™. Data treated with this program included mean values for cow throughput (n=24 observation periods/farm), as well as individual cow duration (n=360 cows/farm at entry and n=240 cows/farm at exit), sum of each behaviour recorded (n=360 cows/farm at entry and n=240 cows/farm at exit), frequency for rotary stop (n=360 cows/farm at entry and n=240 cows/farm at exit) and rotary stop duration (n=360 cows/farm at entry and n=240 cows/farm at exit).

The statistical model used to search for significant differences between the rotaries was Mixed model (Proc Mixed) with the estimation method Restricted Maximum Likelihood (REML). Factors included in the Mixed model for entry duration is rotary, feeding and cow locator. Feeding was tested separately for the PR2100 only since this rotary model is the only one that has the possibility of feeding. For exit only rotary was included in the Mixed model. Cow durations and cow throughput are presented as Least Square Means (LSM). A logistic transformation model (Proc Glimmix) for binomial data was used to test if there was a significant difference of cow behaviours and use of rotary between the two rotary models compared. At entry ten behaviours were tested and at exit 12 behaviours were tested. At entry the model did not fit for two behaviours due to few recordings. For use of rotary three factors were tested at entry and four at exit. Cow behaviours and use of rotary are presented as arithmetic mean values.

6. Results

6.1 Individual cow duration

The time taken for each cow to exit the rotary was significantly shorter in the PR3100HD than in the PR2100 (p<0.01, F=27.35, Figure 4). The time it took for the individual cows to enter the rotary platform was not significantly different between the two rotaries compared (n.s., F=1.00, Figure 4). The cow locator in the bail had no significant effect on individual cow entry time (n.s., F=0.29). During the direct observation it was noted that cows in a group of first lactation cows tended to lift and put down their front hooves several times before they entered. It was also noted during the video analysis that the majority of the cows on all farms were standing and waiting before the bail was available to enter. In the PR2100 the cows seemed to be waiting for longer periods.

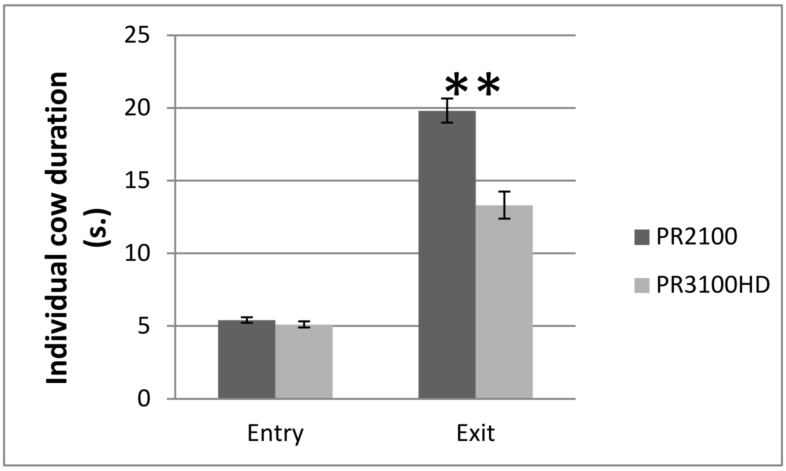

Figure 4. Least Squares Means (±SE) for individual cow entry time (n=360 cows/farm) and exit time (n=240 cows/farm) in seconds in the parallel rotaries PR2100 (n=5 farms) and PR3100HD (n=4 farms).

Mean individual cow entry time per farm varied from 4.8 to 6.1 s and the shortest entry time was found on farm I that had the PR3100HD (Appendix 5). The shortest individual entry time was 2 s and the longest 25 s. Mean individual cow exit time per farm varied from 11.3 to 22.8 s and all of the shortest exit times were found in the PR3100HD (Appendix 5). The shortest individual cow exit time was 4 s and the longest 60 s. No cow was observed for longer than 60 s at the exit. All farms with the PR2100 had between four to 12 cows that reached 60 s while only three farms with the PR3100HD had one cow per farm that reached 60 s. On the last farm with the PR3100HD a maximum of 40 s was reached during exit.

When comparing feeding with no feeding in the PR2100 only, this had no significant effect on the individual cow entry time (n.s., F= 6.32). Mean individual entry time with feeding was 5.1 (± 0.19) s and without feeding 5.9 (± 0.23) s.

6.2 Cow throughput

The cow throughput time was significantly shorter in the PR3100HD compared to the PR2100 ($p<0.05$, $F=9.69$). The Least Squares Means (LSM) in the PR3100HD was 13.5 min per 60 cows while LSM in the PR2100 was 18.8 min per 60 cows (Figure 5A). The shortest individual duration for 60 cows was 10.0 min and the longest duration was 29.0 min. When the throughput was converted to cows per h it was significantly higher in the PR3100HD ($p<0.05$, $F=11.95$) with a LSM of 277.7 cows per h while the LSM of cows per h in the PR2100 were 196.9 (Figure 5B). The highest measured throughput was 360.0 cows per h and the lowest throughput was 124.1 cows per h.

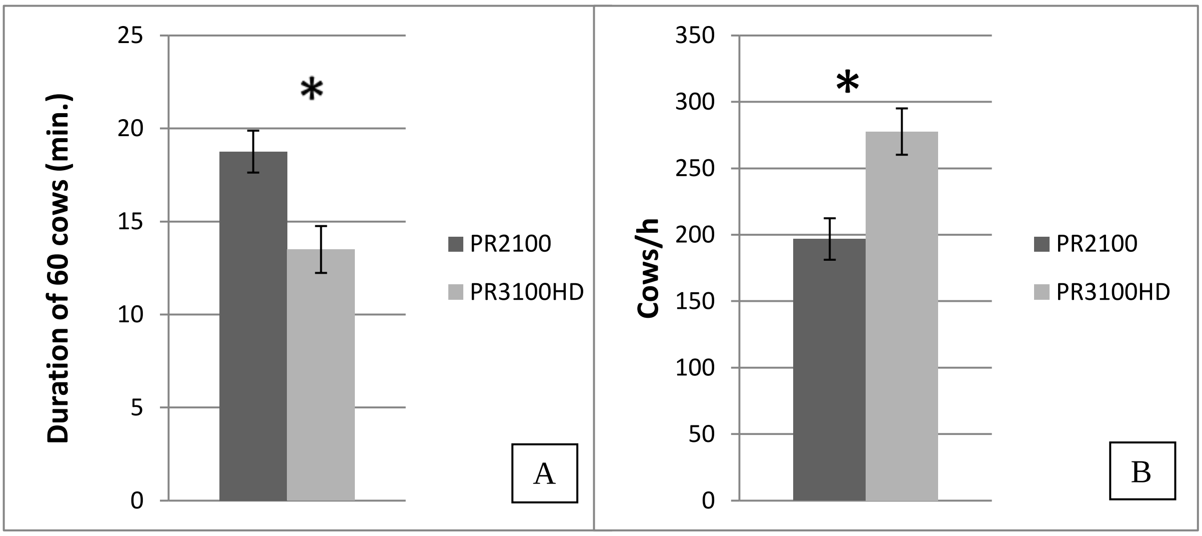

Figure 5. Least Squares Means (±SE) for cow throughput in minutes (A) and in cows/h (B) in the parallel rotaries PR2100 (n=5 farms) and PR3100HD (n=4 farms).

In each of the 24 observation periods a group of 60 cows passed during a mean duration of 11.7-23.6 min (Table 4). This corresponds to a cow throughput from 162.3 to 310.8 cows per h (Table 4). In ALPRO™ and DelPro™ the cow throughput was from 124.7 to 260.2 cows per h (Table 4) and included all cow groups during the whole milking session and time between the milking groups. The difference of cows per h between video observations and ALPRO™ or DelPro™ measures was 12-35 % (Table 4).

Table 4. Mean cow throughput (±SE) presented as group duration in minutes (n=60 cows/session, n=24 sessions/farm) and converted to cows/h at each farm A-I compared to ALPRO™ and DelPro™ cows/h and the difference between cows/h from video recordings and ALPRO™ or DelPro™

Farm	Group duration	Cows/h	ALPRO™/DelPro™ cows/h	ALPRO™/DelPro™ difference
PR2100				
A	22.58 (0.62)	162.33 (4.61)	135.83	16 %
B	18.98 (0.34)	191.11 (3.51)	160.33	16 %
C	16.15 (0.38)	225.77 (5.27)	178.11	21 %
D	16.81 (0.31)	215.89 (4.16)	190.17	12 %
E	19.27 (0.47)	189.23 (4.37)	124.67	34 %
PR3100HD				
F	11.67 (0.17)	309.95 (4.15)	205.83	34 %
G	13.44 (0.45)	274.66 (8.89)	228.11	17 %
H	17.06 (0.53)	215.40 (6.24)	140.00	35 %
I	11.83 (0.39)	310.80 (8.76)	260.22	16 %

The number of cows per h in ALPRO™ and DelPro™ was lower if there were more empty bails and/or more time during changes of milking groups. The number of empty bails was different between the farms because some farms mixed the last cows in one group with the first cows in the next group leaving in practice no empty bails between milking groups. Additionally the number of milking groups per farm varied between two and 16. Number of cows per h was also lowered by more stops in the rotary and longer stop durations. The highest differences were found on farm C, E, F and H (Table 4). This means that farm C, E, F and H had a lower milking efficiency when the whole milking session was taken into consideration. On farm C and E it was observed during the direct observation that the rotary was stopped during milking group changes when the exit lane needed to be closed for several minutes. When the exit lane was closed it became crowded with cows and there were no more space for new cows to exit the rotary. The reason for closing the exit lane during changes of milking groups were because the cows were herded in the same lane to and from the rotary or because some cow groups needed to cross the exit lane to pass between the rotary and the housing group. Farm F had the highest number of cow groups which gives more time in total for group changes. On farm H it was one cow group with mastitis that had *Mycoplasma bovis.* To avoid spread of decease between milking groups the whole rotary was cleaned for 20 min before the next cow group could enter the rotary. These were the reasons for the lower throughput recorded in ALPRO™ and DelPro™.

One rotary lap excluding stops took 10-16 min depending on rotary size and speed. Number of cows per h tended to increase with increasing rotary speed. The fastest speeds were measured on farm C, F, G and I. Compared to the PR2100 the PR3100HD was set at a faster rotary speed, except for farm H. The PR3100HD was set at a constant speed during the whole milking. Farm B was also set at a constant rotary speed but with a faster speed during midday milking and a slower speed during morning milking. Farm A, C, D and E with the PR2100 could have different speed during the milking session depending on operator and cow group. The measured rotary speeds in s per bail for each farm at a random selected rotary lap during morning milking were 16 (A), 18 (B), 14 (C), 15 (D, E, H), 11 (F) and 10 (G, I). During the midday milking farm B had the speed 14 s per bail. These measures were excluding rotary stops.

6.3 Use of rotary

The number of empty bails in the rotary, cows on second rotary lap, running the rotary backwards and herding of the cows at exit for the individually observed cows during entry (n=360 cows/farm) and exit (n=240 cows/farm) are presented in Table 5 and as % in Figure 6 for the PR2100 and the PR3100HD respectively.

Table 5. Mean number of recorded (±SE) empty bails, cows on a second rotary lap, times the rotary was run backwards during entry (n=360 observations/farm) and exit (n=240 observations/farm) and times the staff was herding the cows during exit in the rotaries PR2100 (n=5) and PR3100HD (n=4)

	Entry		P-	Exit		P-
Rotary	**PR2100**	**PR3100HD**	**value**	**PR2100**	**PR3100HD**	**value**
Empty bail	8.0 (2.78)	9.3 (2.39)	n.s.	9.0 (2.10)	1.8 (1.11)	0.03
Second lap	7.2 (3.99)	7.5 (7.17)	n.s.	2.4 (1.69)	5.0 (4.67)	n.s.
Back rotary	1.4 (0.245)	0.3 (0.25)	n.s.	4.4 (1.94)	0.5 (0.50)	n.s.
Staff herding	-	-	-	4.2 (2.01)	3.0 (2.00)	n.s.

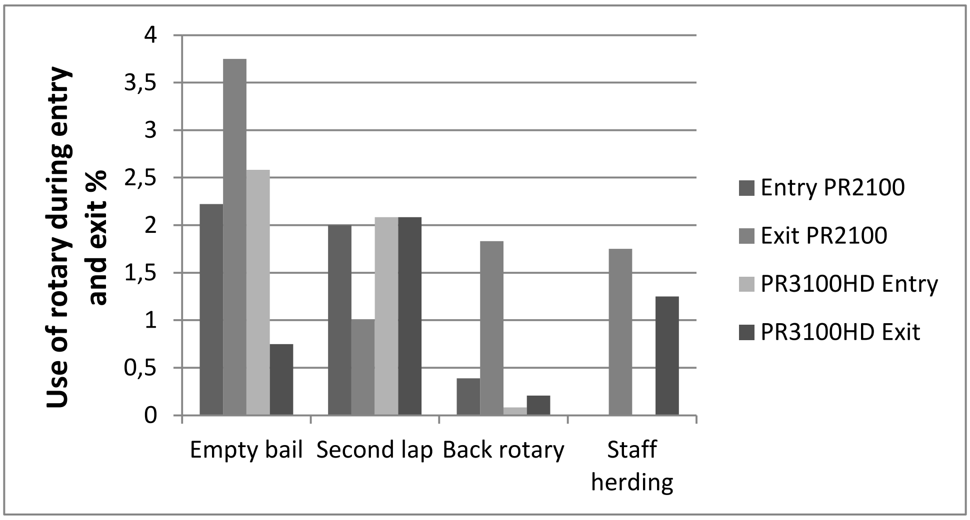

Figure 6. The number of empty bails in the rotary, cows on second rotary lap, running the rotary backwards and herding of the cows at exit during entry (n=360 cows/farm) and exit (n=240 cows/farm) for the PR2100 and PR3100HD respectively.

There was no significant difference between the two rotary models at entry for any parameter (Table 5). Both rotary models each had one farm with the highest number of empty bails (farm B and I, Appendix 6) as well as the highest number of cows on second rotary lap (farm E and G, Appendix 6). At exit a significant difference was found between the two rotary models for empty bails ($p<0.05$, $F= 7.31$, Table 5). No significant difference was found for cows that took a second rotary lap, number of times the rotary was run backwards or number of times the staff was herding the cows at the exit for the observed cows.

Overall the measured parameters in the rotary were more variable between the farms than the rotaries (Appendix 6). Due to few numbers of observations the result was not significant except for empty bails at exit. Number of empty bails was highest on farm B at both entry and exit (Appendix 6). Cows taking a second rotary lap were highest on farm E and G at both entry and exit (Appendix 6). Running the rotary backwards at exit was observed at the highest frequency on farm E (Appendix 6). Herding of cows at the exit occurred in both PR2100 and PR3100HD and varied between the farms (Appendix 6). When the staff was herding the cows in the exit area or the exit lane they were walking behind the cows, waving their arms/stick or touching the cows while whistling, talking or shouting. During the direct observation it was observed that herding mainly occurred during changes of milking groups at the exit.

6.5 Cow behaviours at entry

The only significant behavioural difference between the two rotary models during entrance to the rotary was found for "pushed". There were significantly more cows that got pushed by another cow during the entry to the rotary platform in the PR3100HD compared to the PR2100 (Table 6). The other behaviours were not significantly different between the two rotary models (Table 6). Almost all cows entered voluntary and almost no cow performed chin rest so it was not possible to test these two behaviours in the model. The numbers of performed behaviours during entry are presented in Table 6 and as % in Figure 7 for the PR2100 and the PR3100HD respectively.

Table 6. Mean number (±SE) of recorded cow behaviours during entry (n=360 cows) to the two rotary models PR2100 (n=5 farms) and PR3100HD (n=4 farms)

Rotary	PR2100	PR3100HD	F-value	P-value
Voluntary	350.2 (1.28)	334.0 (14.76)	a	a
Sniff	201.8 (26.57)	148.0 (49.48)	0.97	n.s.
Pushed	1.0 (0.55)	25.5 (14.57)	13.86	0.01
Head push	2.6 (1.21)	2.8 (1.70)	0.01	n.s.
Ruminate	36.4 (13.44)	20.5 (10.72)	0.66	n.s.
Rub	2.4 (0.75)	0.8 (0.75)	2.34	n.s.
Lick	1.0 (0.45)	0.5 (0.29)	0.69	n.s.
Chin rest	0.8 (0.37)	0.0 (0.00)	a	a
Eliminate	0.4 (0.25)	1.3 (0.95)	0.77	n.s.
Slip	0.2 (0.20)	1.3 (0.63)	2.57	n.s.

[a] The model did not fit

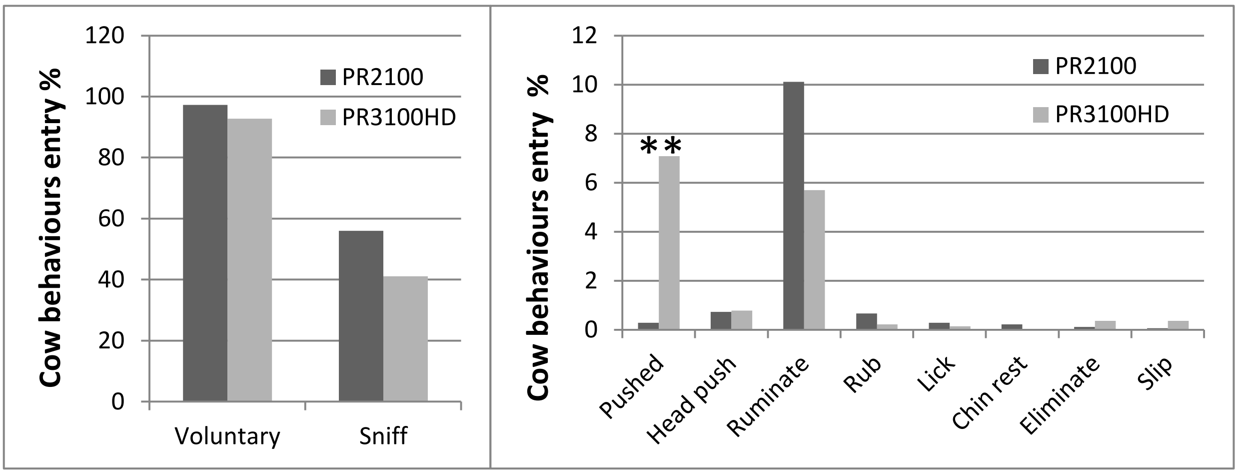

Figure 7. Cow behaviours in % presented for the behaviours "voluntary", "sniff", "pushed", "head push", "ruminate", "rub", "lick", "chin rest", "eliminate" and "slip" during entry (n=360) for the rotary models PR2100 (n=5 farms) and PR3100HD (n=4 farms) respectively.

The majority of all cows entered the rotary voluntary, only 0 to 14 cows were pushed on the rotary by another cow, except at farm G where 69 cows were pushed (Appendix 7). Farm G with the highest frequency of pushing also had the lowest frequency of sniffing (Appendix 7). Sniffing and ruminating was overall the most common behaviours performed (Table 6). The majority of cows that were recorded as sniffing were holding their heads low above the flooring in the rotary before the bail was completely open and available for them to enter. The cow behaviours “lick self”, “scratch”, “kick”, “kneel”, “fall”, “lie down”, “mounting attempt”, “mounting” and “limp” were not observed in any cow on the videos directly before or during entry to the rotary on any farm. However both “mounting”, “kneel” and “fall” was observed a few times during the direct observation at some farms in the waiting area.

6.6 Cow behaviours at exit

The only significant difference between the two rotary models during exit from the rotary was found for “bump” (Table 7) that was more common in the PR2100. “Stand” also tended to be significantly higher in the PR2100 (Table 7). The other behaviours were not significantly different between the two rotary models (Table 7). The numbers of performed behaviours during exit are presented in Table 7 and as % in Figure 8 for the PR2100 and the PR3100HD respectively.

Table 7. Mean number (±SE) of recorded cow behaviours during exit (n= 240) in the two rotary models PR2100 (n=5 farms) and PR3100HD (n=4 farms)

Rotary	**PR 2100**	**PR 3100**	**F-value**	**P-value**
Voluntary	236.0 (2.79)	236.8 (6.21)	0.66	n.s.
Sniff	24.8 (4.16)	14.5 (4.50)	2.50	n.s.
Bump	109.2 (10.37)	72.3(9.95)	6.68	0.04
Stand	120.0 (17.27)	71.5 (14.00)	4.18	0.08
Push	44.2 (8.86)	41.0 (7.34)	0.05	n.s.
Ruminate	57.0 (18.12)	79.8 (8.27)	1.37	n.s.
Eliminate	3.8 (2.33)	3.0 (1.23)	0.00	n.s.
Lick self	13.2 (12.70)	0.3 (0.25)	1.15	n.s.
Throw head	11.0 (9.57)	0.3 (0.25)	1.02	n.s.
Rub	1.2 (0.74)	1.0 (1.00)	0.12	n.s.
Slip	0.6 (0.245)	1.0 (0.41)	0.47	n.s.
Limp	0.8 (0.80)	1.5 (0.96)	0.45	n.s.

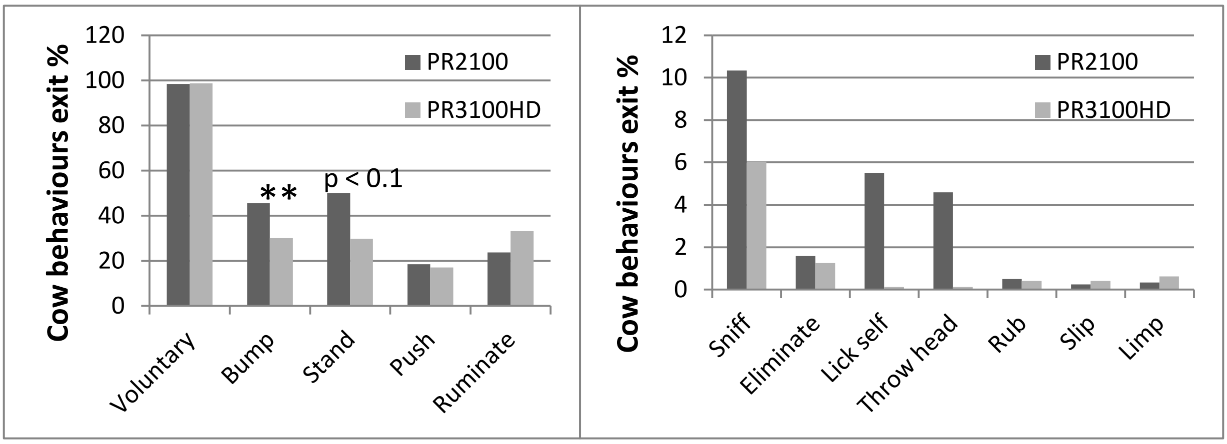

Figure 8. Cow behaviours in % presented for the behaviours "voluntary", "bump", "stand", "push", "ruminate", "sniff", "eliminate", "lick self", "throw head", "rub", "slip" and "limp" during exit (n=240) for the rotary models PR2100 (n=5 farms) and PR3100HD (n=4 farms) respectively.

The majority of all cows also left the rotary voluntary. The frequency was a bit lower on farm E and G where 9 to 19 cows took a second rotary lap instead (Appendix 6 and 8). Sniffing on the housing/other cows, bumping into another cow, standing still and get pushed by other cows during the exit was all observed in a higher frequency on farm A (Appendix 8), indicating a potential problem of cow throughput. However, the highest number of recordings of cows standing still was found on farm C. Licking self and throw head mainly occurred on farm C as well (Appendix 8). During the direct observation it was noted that the cows had flies on their back that caused the cows to stop and chase them away as soon as they had left the rotary. Furthermore these behaviours at farm C was recorded more often during the midday milking compared to morning milking. Eliminating during exit was more common on farm B (Appendix 8), but during the direct observation many cows on other farms were observed eliminating in the last bails in the rotary before they exited. This was not captured by the video cameras. Other behaviours were not commonly observed and are quite equally distributed between the two rotary models as shown in Table 7. The behaviours "chin rest", "fall", "lie down", "kneel" and "kick" was not observed in any cow during exit from the rotaries on any farm.

6.7 Rotary stops

When calculating the % of rotary stops for the observed cows during entry and exit it was found that the PR2100 had more stops at both entry and exit with 16-21 % compared to 5-6 % in the PR3100HD. The reason for rotary stops were mainly caused by other reasons than cow traffic and often lasted below 30 s in both rotary models (Table 8).

Table 8. The % of total number of stops, stops caused by cow traffic and stops caused by other reason along with % of stop duration for stops up to 30 s, stops between 31 to 60 s and stops above 60 s for the observed cows at entry (n=360 cows/farm) and exit (n=240 cows/farm) respectively for the two rotary models PR2100 (n=5 farms) and PR3100HD (n=4 farms)

	Entry		**Exit**	
Rotary	**PR2100**	**PR3100HD**	**PR2100**	**PR3100HD**
Rotary stop				
Total no. stops	15.61	4.69	20.98	6.05
Cow traffic	3.50	0.93	1.94	0.42
Other reason	12.11	3.77	19.04	5.63
Stop duration				
< 30 s stops	10.78	2.49	14.32	4.46
31-60 s stops	2.78	0.78	5.14	0.74
>60 s stop	2.17	1.42	1.43	0.74

Rotary stops that were caused by other reasons than cow traffic were most often not possible to determine from the camera view but was observed during the direct observations. It was noted that these stops varied between the farms depending on farm routines. The most common reasons for rotary stops were that a cow had not finished milking before the exit, the milking staff stopped to mark a cow or write notes about a cow, to change udder towels at the washing machine, to bucket milk in the rotary, to re-attach clusters or to re-attach milk tubes on the cluster. Reasons to re-attach the cluster were because the cow had kicked it off or that the cluster was sucking air.

6.7.1 Entry

The farm with the highest number of rotary stops at the entry was farm A that also had the highest proportion caused by cow traffic as well as farm E (Appendix 9). On farm A other reasons for rotary stops were to catch up milking, take notes on cows and to change udder towels. On farm E only one person was milking the cows in the rotary and other reason for stopping than due to cow traffic was mainly to re-attach clusters on cows. Farm F and I had the fewest rotary stops (Appendix 9). Farm A had both shorter and longer stops while the other farms mainly had less than 30 s stop durations (Appendix 9). Waving or touching the cow with the hand from beside or behind to make it enter was more often used in the PR2100 with a maximum of 12 times on one farm compared to maximum one time per farm in the PR3100HD (Appendix 9). A towel or stick was not used more than two times on any farm to make the cows enter and water spray was never used (Appendix 9).

6.7.2 Exit

The farms with the highest number of rotary stops at the exit were farm A and E (Appendix 10) as for the entry. Farm E had the highest proportion of rotary stops caused by cow traffic (Appendix 10) that was mainly because a cow did not exit the rotary. Even at the exit farm A had both shorter and longer stops while stops below 30 s were more common overall (Appendix 10). It was not common to use a tool or hand to make the cows exit; it was observed a maximum of three times respectively (Appendix 10).

6.8 Direct observation in the exit area

The exit area was in all herds more crowded during some periods of the milking shift. When it was crowded the cows did not start to move before another cow was pushing hard to get through or when the staffs were herding the cows. In general many of the cows had very limited space to back off the rotary early and turn around and this gave a longer exit time on average. Most of the cows that bumped into another cow when they backed off the rotary were standing still for several seconds before they turned around. Up to three cows could back off the rotary platform during the same time which gave no space for these cows to turn around in any direction. This also seemed to be more common in the PR2100 that did not have the exit bow. It was noted that the majority of the cows started to back off the rotary from the first bail but they could not leave the rotary because the exit area was too crowded. On the majority of the farms during each milking session it was also some cows that backed off the rotary in the last bail and stayed along the wall that divided the cow from the entry lane. At this position the cow could stay for several minutes, ruminating, before turning around.

During the direct observations it was also noted that the major problems with the cow traffic was caused in the exit area when the cows stayed after they had turned around and hence this was not covered by the data analysis. When the cows stayed in the exit area they were often positioned at specific places. On six farms the cows were observed to stop where the flooring surface changed from rubber to solid concrete or slatted concrete and from solid concrete to slatted concrete in the exit lane (Appendix 2). All farms had 2-10 m to the first angled corner (Appendix 2) where the cows also could get crowded. A few cows were often positioned along the rail or wall that divided the cows from the waiting area. At this location the cows had turned around and stood ruminating or made contact with the cows in the waiting area. On the majority of the farms this area was also where the rubber mat ended or just before the exit area became the exit lane after an angled corner. On eight of the nine farms parts of the exit lane wall consisted of rails or was low enough for the cows to see above. On the farms that had rails in the exit area that divided the cows from the waiting area or a personnel walkway the cows could put their head in, socializing with other cows, turn their side across the exit lane and thereby cause a blockage. On the farms that had low exit walls the cows stopped to look at the cows in the selected cow group beside the lane, staff passing by or out in the yard. This also caused a blockage in the exit lane because at seven farms the exit lane was only wide enough for one cow (Appendix 2). When some cows blocked the exit lane the exit area could get crowded all the way up to the rotary, causing problems for the following cows to exit the rotary.

A change in the cow traffic was noted towards the end of the milking session. When the last cows had entered the rotary and the waiting area was empty almost no cows stayed in the exit area. At some of the farms the rotary was set at a higher speed during this time and the operators started to clean the rotary with water spray. It seemed like the cows exited faster the faster the rotary was turned.

7. Discussion

It was a significantly higher cow throughput in the PR3100HD compared to the PR2100. There was no significant difference in cow entry time between the two rotary models compared but the cows were pushed by other cows significantly more during entry in the

PR3100HD. The individual cows exited the PR3100HD significantly faster than the PR2100. The cows were backing into other cows significantly more and showed a tendency of standing still more at the exit in the PR2100 causing problems for the cow throughput. The higher frequency of cows standing still, cows licking themselves and throwing their heads back at the exit on farm C could be explained by that the cows had considerable number of flies on their back that caused the cows to stop and chase them away.

7.1 Entry to rotary

The statistical analysis showed no differences in individual cow entry time between the PR2100 and the PR3100HD, but it was noted during the video analysis and direct observation that the cows seemed to be waiting for longer periods before they entered the platform in the PR2100. The PR2100 was run at a slower speed compared to the PR3100HD which can explain the potentially longer waiting periods for the cows in the PR2100. If the measure of cow entry time had included the total continuous time between two cows that entered the rotary it had probably been faster in the PR3100HD due to the faster rotary speed. When the bail was completely open the cows entered during the same average time. In the PR3100HD the rotary was set at a constant speed during the whole milking session, also at farm B with the PR2100. In the other PR2100 on the other hand the speed could vary during the milking session depending on cow group and operator choice. This means that the measured speed in the PR2100 may not be relevant for the whole milking session. Moreover the cows were observed to get pushed significantly more by other cows during entry in the PR3100HD. This was probably due to the 1.5 cow entry which can cause more competition between the cows when they could pass each other before they entered the rotary. The possibility for other cows to pass could also be beneficial for the cow throughput if there is a slow cow blocking the entrance. The majority of the stops were however not due to problems with cow traffic but the cows were a bit more influenced by the staff in the PR2100 where they used the hand more times to make the cow enter. When the cows walked behind each other in the one cow entry lane to the PR2100 there was less pushing by other cows which could explain that slow cows got an extra touch by the milking staff instead.

7.2 Feeding in rotary

Even if feeding had no significant effect on individual cow entry time in the PR2100 the three farms with feeding had the shortest entry time within the PR2100. On the other hand the cows entered faster on some farms that had the PR3100HD. It is possible that feeding in the rotary had a positive effect on the cow entry time but more farms are needed in order to investigate this further. In previous studies feeding in the rotary increased the number of occupied bails in the rotary and it was concluded that feeding can be used to avoid delays related to cow traffic (Kolbach et al., 2013). According to the present study the cow entry time did not seem to be the limiting factor for cow traffic since the cows adapted to the rotary speed and most of the rotary stops were operator related mainly depending on other reasons than cow entry.

7.3 Cow throughput

Due to few number of farms and the variation of milking times between the farms it was not possible to test if there was a difference in cow throughput or entry and exit times between different milking times of the day, e.g. between morning, midday and evening milking.

It was significantly higher cow throughput in the PR3100HD compared to the PR2100. This could be affected by the on average faster rotary speed and larger rotaries in the PR3100HD. However, when comparing different rotary sizes the highest throughput was not only found in the largest rotaries. In the literature on the other hand the cow throughput tended to increase linearly with increasing rotary size (Nitzan et al., 2006; Edwards et al., 2013). The cow throughput is also affected by pre-milking routines (Smith et al., 1998) and number of operators (Edwards et al., 2013). There was on average one extra operator in the PR3100HD so the milking tasks could be divided between more persons. Therefore the higher cow throughput in the PR3100HD could have been achieved by the higher rotary speed in the PR3100HD that was possible due to the on average one extra operator. Another factor that affects the efficiency in the rotary is the individual cow production and duration of milking cluster attachment (O´Brien et al., 2012). It is likely that farms with three milking sessions per day have a lower amount of milk per session compared with farms that only milk two times per day. This factor had on the other hand probably no influence on the result since two or three milking sessions was equally distributed on both farms with the PR2100 and the PR3100HD. Nevertheless it has to be mentioned that the cow throughput seemed to be more dependent on individual cow exit times together with the layout of the exit area and exit lane rather than the above mentioned factors.

A slight difference in cow throughput was expected between the video recordings and ALPRO™ and DelPro™ because these measures took the whole milking session into account which also included the time between group changes and cow groups with potentially lower throughput. The difference was however higher on some farms. This higher difference that was observed on farm C, E, F and H could be explained by management routines and barn layout. On farm C and E the exit lane needed to be closed for several minutes during group changes. When the exit lane was closed it became crowded with cows and there was no more space for new cows to exit from the rotary which caused a rotary stop. This is a problem that could have been avoided if the cows had separate lanes for transportation to and from the rotary and if no cow group needed to cross the exit lane to get to and from the housing group. When planning for building of a rotary milking system or installing a rotary in existing buildings it is important to take the whole barn layout into consideration in order to optimise the cow traffic to and from the rotary. It is also important to carefully consider the grouping of cows and locations of different cow groups. If the cows have to take longer or more complicated routes than necessary this will increase the labour input during milking. It will also decrease the total milking efficiency in the rotary if transportation of cows leads to additional rotary stops.

On farm F the cows were milked in 16 different groups. With a higher number of groups there is more time in total that is not used for milking during group changes if the groups need to be kept separately in the rotary. On farm F there was always some empty bails in the rotary between each milking group to avoid mixing of cows in the exit area. On farm H the lower throughput was explained by cleaning of the rotary after a group of sick cows. Milking cow groups with special needs as sick cows or newly calved cows in the rotary is therefore associated with a lower milking efficiency in the rotary. If the goal on the farm may be to have a higher cow throughput in the rotary it could be improved by milking cow groups with special needs separately. This will however require investments in an alternative milking system and will probably not improve the total labour input on the farm. The measures of cow throughput according to ALPRO™ and DelPro™ are dependent on farm management routines and therefore it should only be used to compare the cow flow within farms and not between farms.

7.4 Rotary stops

In total it was more stops in the PR2100 but the majority of the stops were caused by other reasons than cow traffic. The proportion of cow related rotary stops of total number of rotary stops was up to 2.5 % higher in the PR2100. This could be affected by different farm management routines. In general there were fewer cows on farms with the PR2100, about 400 cows, compared to farms with the PR3100HD, about 1000 cows. The only exception is farm D that had about 1000 cows in a PR2100. Farm D also had among the fewest stops of the PR2100 rotaries. In general one less person was working during the milking session in the PR2100. It is therefore possible that farms with the PR2100 and fewer cows combined milking with other tasks as checking health and breeding status and that the PR3100HD with larger farms and more operators were more specialized on milking tasks. It is also likely that other rotary stops can be a reason for more cow related rotary stops. If the rotary is stopped more times the cow flow is disrupted because the cows have to wait for longer times and stand still more before they can enter the rotary. This seems to affect the cow flow negatively since the cows need to be set in movement again when the rotary starts compared to when there is a continuous cow flow onto the rotary. If there also is a continuous cow flow during the exit the cows in the exit area might also be more stimulated to move forward when new cows are coming and might even push the cows towards the exit lane. In order to create continuous and steady cow flow in the rotary all stops should be avoided.

7.5 Cow traffic in the exit area

The direct observations at all farms showed that there is a potential for improvements of the cow traffic by development and further adaptations of the layout in the exit area and exit lane. Many of the cows were observed to stay in the exit area along the wall to the waiting area, where the flooring changed, at corners, claw bath and selection gates. It has been concluded that dairy cows prefer to walk and stand on rubber mats over concrete flooring (Telezhenko et al., 2007) which can explain that the cows in the present study tended to stop where the rubber mat ended. Telezhenko et al. (2007) compared solid rubber mats with solid concrete in the waiting area and slatted and solid rubber mats were tested against slatted concrete in the walkway. When the cows had the possibility to choose, 64-69 % of the cows preferred rubber flooring rather than concrete flooring. According to the study the cows also favoured solid rubber mats over slatted rubber mats (Telezhenko et al., 2007). In another study the cow preference for a soft track surface was investigated (Gregory & Taylor, 2002). In 96 % of the occasions the cows preferred woodchip overlay over the conventional hard-core track which further highlights the influence of flooring surface on dairy cattle.

According to Grandin (2012) eliminations of distractions facilitate the movement of animals. Different aspects are suggested in order to make practical improves for beef cattle moved in slaughter plants. Some of the suggestions include eliminating reflexions on wet floor and shiny metal, blocking sunbeams and avoiding dark spots since the animals attracts to light (Grandin, 2012). It is also promoted to block the animal’s vision of distracting objects by using solid walls in the walkway and holding area since this improves animal movement (Grandin, 1980; Grandin, 2012). For cattle handling facilities it is recommended to use a curved race so it does not seem to appear a dead end for the animal (Grandin, 1997). Furthermore it is stated that animals will hesitate or refuse to move across changes of flooring (Grandin, 2012). Even if housing methods and temperament differ between beef cattle and dairy cows it is likely that many of these methods can improve dairy cow traffic if they are adopted. Many of the problems that occur during moving of beef cattle also seems to cause problems with cow traffic in milking systems for dairy cows according to the present study. If small changes can be done to improve cow traffic during milking it will likely reduce the total time spent on milking activities and thereby free more time to spend on other tasks.

7.6 Future research

More farms are needed in order to compare how the cow throughput is influenced by factors as flooring material, back off devices, exit lane layout, use of claw bath and selection gates. Only nine individual farms with unique combination made it impossible to statistically compare and evaluate the influence of these factors. In future studies it would be interesting to investigate the effect of exit area and exit lane layout on the cow flow. These studies should include the influence of higher walls in exit lanes, different flooring in exit areas and different distance to claw bath and selection gates. The effect of one factor should be evaluated within a farm where all other factors are the same to be able to draw conclusions about how that factor alone affects the cow throughput and cow behaviour.

7.7 Practical adaptations

According to the present study and previous research some practical adaptations to improve dairy cow traffic during milking are suggested. The walls in the exit lane should be higher and solid in order to block the cow´s vision from surrounding areas and distracting objects. The exit lane should be wide enough for two cows and without any corners or angles the first meters in order to create the possibility for a higher cow flow from the exit area to the exit lane. Any changes of flooring should be avoided between the rotary and exit lane since these changes can cause the cows to stop and lead to a blockage at the rotary exit. Furthermore any obstacles such as claw bath, selection gates and other equipment should be placed further away from the rotary exit area or kept out of sight.

8. Conclusions

In conclusion there was a higher cow throughput and faster individual cow exit times in the PR3100HD. The average cow throughput was 278 cows per h in the PR3100HD and 197 cows per h in the PR2100. The exit time and cow throughput is believed to be improved by the exit bow that comes together with the PR3100HD only. In the PR2100 the cows were backing into each other significantly more and showed a tendency of standing still more. In addition to the exit bow it was also observed that the layout of the exit area and exit lane had a major influence on the cow traffic. Cow exit time appears to be the single largest factor that limits the cow throughput.

There was no significant difference in individual cow entry time and the entry time did not seem to be a limiting factor for high cow throughput. The cows were pushed by other cows significantly more in the PR3100HD and this is suggested to be affected by the 1.5 cow entry that was only available in that rotary model.

In order to further improve the cow throughput and cow traffic in rotary milking systems factors as flooring, exit lane walls, positions of corners, claw bath and selection gates has to be taken into consideration.

9. Acknowledgements

First of all I would like to express my sincere thanks to my main supervisor Lena Lidfors at SLU and my co-supervisors Klaus Aye and Charlotte Hallén Sandgren at DeLaval for valuable discussions and inputs and for the fully support during this thesis. I would like to direct a genuine thank to the participating farms and employees for sharing information about their farms and milking routines and for making this study possible. I would also like to thank my contact persons at DeLaval, Björn Johansson, Leif Mortensen, Martin Wiedemann and Juergen Friebel for arranging the contacts with the farms and providing information about the farms in Sweden, Denmark and Germany. I would also like to show my appreciation to all the service technicians for assisting me during the installation of the camera equipment and to Göran Eriksson and Mario Aguado for helping me to get the farm data from ALPRO™ and DelPro™.

In addition, sincere thanks to Chris Oliver, Brian Bell and Steve Mattox at DeLaval for sharing information about the two rotary systems and for giving important input during the planning of the survey. Finally I would also like to thank Claudia von Brömsen at SLU for assisting me during the data analysis and providing me with statistical models.

10. References

Berry, D.P. and McCarthy, J. (2012). Genetic and non-genetic factors associated with milking order in lactating dairy cows. Applied Animal Behaviour Science 136, 15– 19.

Dijkstra, C., Veermäe, I., Praks, J., Poikalainen, V., Arney, D.R. (2012). Dairy Cow Behavior and Welfare Implications of Time Waiting Before Entry Into the Milking Parlor. Journal of Applied Animal Welfare Science 15:4, 329-345.

Dodzi, M.S. and Muchenje, V. (2011). Avoidance-related behavioural variables and their relationship to milk yield in pasture-based dairy cows. Applied Animal Behaviour Science 133, 11– 17.

Edwards, J.P., Lopez-Villalobos, N., Jago, J.G. (2012). Increasing platform speed and the percentage of cows completing a second rotation improves throughput in rotary dairies. Animal Production Science 52, 969-973.

Edwards, J.P., Jago, J.G., Lopez-Villalobos, N. (2013). Large rotary dairies achieve high cow throughput but are not more labor efficient than medium-sized rotaries. Animal Production Science 53, 573-579.

Galindo, F. and Broom, D.M. (2000). The relationships between social behaviour of dairy cows and the occurrence of lameness in three herds. Veterinary Science 69, 75–79.

Grandin, T. (1980). Observations of cattle behaviour applied to the design of cattle-handling facilities. Applied Animal Ethology 6, 19-31.

Grandin, T. (1997). The design and construction of facilities for handling cattle. Livestock Production Science 49, 103-l 19.

Grandin, T. (2012). Auditing animal welfare and making practical improvements in beef-, pork- and sheep-slaughter plants. Animal Welfare 21(S2): 29-34.

Gregory N.G. and Taylor, O.D. (2002). Dairy cow preference for a soft track surface. New Zealand Veterinary Journal, 50:2, 83-83

Ishiwata, T., Uetake, K., Kilgour, R. J., Tanaka, T. (2005). 'Looking up' behavior in the holding area of the milking parlor: its relationship with step-kick, flight responses and productivity of commercial dairy cows. Animal Science Journal 76, 587–593

Ketelaar-deLauwere, C.C., Devir, S., Metz, J.H.M., (1996). The influence of social hierarchy on the time budget of cows and their visits to an automatic milking system. Applied Animal Behaviour Science 49, 199–211.

Kolbach, R., Kerrisk, K. L., Garcia, S. C., Dhand, N. K. (2013). Effects of bail activation sequence and feed availability on cow traffic and milk harvesting capacity in a robotic rotary dairy. Journal of Dairy Science 96, 2137–2146.

Main, D.C.J., Barker, Z.E., Leach, K.A., Bell, N.J., Whay, H.R., Browne, W.I. (2010). Sampling strategies for monitoring lameness in dairy cattle. Journal of Dairy Science 93, 1970-1978.

Melin, M., Hermans, G. G. N., 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 Behaviour Science 96, 201–214.

Munksgaard, L., DePassillé, A.M., Rushen, J., Herskin, M.S., Kristensen, A.M. (2001). Dairy cows´fear of people: social learning, milk yield and behaviour at milking. Applied Animal Behaviour Science 73, 15-26.

Nitzan, R., Bruckental, I., Bar Shira, Z., Maltz, E., Halachmi, I. (2006). Stochastic Models for Simulating Parallel, Rotary, and Side-Opening Milking Parlors. Journal of Dairy Science 89, 4462–4472.

O'Brien, B., Jago, J., Edwards, J.P., Lopez-Villalobos, N., McCoy, F. (2012). Milking parlour size, pre-milking routine and stage of lactation affect efficiency of milking in single-operator herringbone parlours. Journal of Dairy Research 79, 216–223.

O'Donovan K., O'Brien B., Ruane D., Kinsella J., Gleeson D. (2008). Labour input on Irish farms and the effect of scale and seasonality. Journal of Farm Management 13, 327–342.

Phillips, C.J.C. and Rind, M.I. (2001). The Effects on Production and Behavior of Mixing Uniparous and Multiparous Cows. Journal of Dairy Science 84, 2424–2429.

Phillips, C.J.C. and Rind, M.I. (2002). The Effects of Social Dominance on the Production and Behavior of Grazing Dairy Cows Offered Forage Supplements. Journal of Dairy Science 85:51–59.

Prescott, N. B., Mottram, T. T., Webster, A. J. F. (1998). Relative motivations of dairy cows to be milked or fed in a Y-maze and an automatic milking system. Applied Animal Behaviour Science 57, 23–33.

Rathore, A. K. (1982). Order of cow entry at milking and its relationship with milk yield and consistency of the order. Applied Animal Ethology 8, 45–52.

Rushen, J., and de Passillé, A. M. (1999). Environmental design for healthier and more profitable cows. Advances in Dairy Technology 11, 319–333.

Rushen, J., De Passillé, A.M.B., Munksgaard, L. (1999). Fear of People by Cows and Effects on Milk Yield, Behavior, and Heart Rate at Milking. Journal of Dairy Science 82, 720–727.

SJV, Jordbruksverket (2013). The Swedish Board of Agriculture. Database for statistics. [online] Available:http://statistik.sjv.se/Dialog/varval.asp?ma=JO0103HKATL&ti=F%F6retag+med+djur+efter+l%E4n%2Friket+och+bes%E4ttningsstorlekar+1998%2D2012&path=../Database/Jordbruksverket/Husdjur/&lang=2

Smith, J.F., Armstrong, D.V., Gamroth, M.J. and Harner, J (1998). Factors affecting milking parlor efficiency and operator walking distance. Applied Engineering in Agriculture Vol. 14:6, 643-647.

Sutherland, M. A. and Huddart, F. J. (2012). The effect of training first-lactation heifers to the milking parlor on the behavioral reactivity to humans and the physiological and behavioral responses to milking and productivity. Journal of Dairy Science 95, 6983–6993.

Taylor, G., van der Sande, L., Douglas, R. (2009). Technical Report For: Smarter Not Harder, Improving Labour Productivity in the Primary Sector p. 1-97. A Joint Dairy InSight (DairyNZ) and Sustainable Farming Fund Project.

Telezhenko, E., Lidfors, L., Bergsten, C. (2007). Dairy Cow Preferences for Soft or Hard Flooring when Standing or Walking. Journal of Dairy Science 90, 3716–3724.

Thomas, C. V., DeLorenzo, M. A., Bray, D. R. (1996). Factors Affecting the Performance of Simulated Large Herringbone and Parallel Milking Parlors. Journal of Dairy Science 79. 1972-1980.

Van Reenen, C. G., Van der Werf, J. T. N., Bruckmaier, R.M., Hopster, H., Engel, B., Noordhuizen, J. P. T. M., Blokhuis, H. J. (2002). Individual differences in behavioral and physiological responsiveness of primiparous dairy cows to machine milking. Journal of Dairy Science 85, 2551–2561.

Österman, S., and Redbo, I. (2001). Effects of milking frequency on lying down and getting up behavior in dairy cows. Applied Animal Behaviour Science 70, 167–176.

11. Appendix

Appendix 1

Table 1. Rotary information for all farms including in which direction the rotary is turned (left/right), type of back off device in the rotary, if the farm use any kind of electricity to back off the cows and if some of the cows are milked in an alternative milking system to the rotary

Farm	**Rotation**	**Back off device**	**Electricity**	**Alternative milking system**
PR2100				
A	Left	Rubber mat, metal	Trained	No
B	Right	Short chains	In chains	No
C	Left	No	Trained	No
D	Left	Rubber mat	No	No
E	Right	No	No	No
PR3100HD				
F	Right	Constant water	No	No
G	Right	Rubber mat	No	Yes
H	Right	Barrel, chains	In chains	Yes
I	Left	Barrel, rubber mat	Turn on	Yes

Appendix 2

Table 1. Flooring material for all farms in the waiting area, at the entry area, on the rotary, at the exit area and in the exit lane. The different materials are rubber mat (R), concrete (C), slatted concrete (S. C), slatted rubber (S. R), asphalt (A) and bricks (B). The distance (m) from the rotary exit to the housing groups, claw bath, selection gate, corners and less steep angles in the exit lane, and the width (m) of the exit lane

Farm	Waiting Area	Entry	Rotary	Exit	Exit lane	Housing	Claw bath	Gate	90°corner	Angle	Exit lane width
PR2100											
A	C	C	R	R	S. C	20-40	7	17	24	7	< 1
B	R	R	R	R	R	25-40	No	23	No	5	< 1
C	R	R	R	R	S. C	40-50	No	13	20	5	< 1
D	C	C	R	R	C	30-100	20	28	6,6	6,5	< 1
E	C	C	C	C	C	25-50	10	20	20	3,5	< 1
PR3100HD											
F	S. R	A	R	A	A + S. R	30-100	20	8	35	10	< 1
G	R	R	R	R	S. C	50-100	42+	42	27	5	2
H	S. C	C	R	C	S. C + R	100-200	20	14	26	5	< 1
I	S. C	C	B	C	S. C	90-120	16	16	18	6	2

Appendix 3

Table 1. Mean values for lactation number, milk yield (MY), average milk duration 7 days (Dur 7 d), days in milk (DIM) and number of cows presented for each milking group at farm A-E with the PR2100 based on ALPRO™ data

Farm	Cow group	No. cows	Lactation no.	MY	Dur 7 d	DIM
A	From calving	166	2.04	30.94	06:13	73.0
A	From pregnant	210	2.09	26.22	05:20	225.2
B	All cows**	301	2.13	28.25	05:20	141.62
C	1st lactation	222	1.23	29.92	04:46	169.81
C	2nd lactation	142	2.35	34.66	05:18	192.47
C	3rd lactation ≥	108	3.01	28.75	04:42	258.64
C	Bucket milking	35	2.46	*	*	52.27
D	High yield	171	2.44	32.90	06:28	109.03
D	High yield	167	2.34	33.09	06:28	41.96
D	Start + lame	45	2.11	27.41	05:22	32.28
D	Start + lame	11	3.18	24.35	05:29	150.73
D	High yield	163	2.03	17.44	04:04	382.01
D	Medium yield	166	2.25	27.58	05:11	167.85
D	Low yield	168	1.95	25.02	04:52	210.42
D	Culling	160	1.73	17.30	03:49	244.17
E	High yield	74	3.014	39.10	06:35	65.74
E	1st lactation	67	1.00	25.22	05:07	180.48
E	Medium yield	138	2.74	25.21	04:49	255.91
E	Treatment	40	2.40	24.10	04:54	332.53
E	Calving + sick	12	2.67	15.36	03:15	85.25
E	Low yield	29	3.14	9.64	03:09	365.59

*Missing data for cow groups with bucket milking
** It was three physical milking groups on farm B but they were recorded as one group in ALPRO™

Appendix 4

Table 2. Mean values for lactation number, milk yield (MY), average milk duration 7 days (Dur 7 d), days in milk (DIM) and number of cows presented for each milking group at farms with the PR3100HD for farm F based on DELPRO™ and farm G-I based on ALPRO™ data

Farm	Cow group	No. cows	Lactation no.	MY	Dur 7 d	DIM
F	Lame	*	*	*	*	*
F	Newly calved	53	0.98	27.19	5:15	29.42
F	Newly calved	42	3.54	35.36	5:55	18.36
F	Insemination	90	2.99	37.59	5:42	89.48
F	Insemination	89	1.90	32.67	5:10	115.36
F	Pregnant	91	1.81	26.28	4:42	254.52
F	Pregnant	91	2.48	26.27	4:50	258.96
F	Pregnant	82	2.23	25.62	5:00	255.28
F	Pregnant	80	1.95	26.19	4:55	251.55
F	Low yield	92	2.83	11.67	4:16	356.28
F	Insemination	93	3.00	37.04	5:37	136.09
F	Insemination	94	2.25	35.74	5:41	133.35
F	Insemination	94	2.25	33.96	5:25	123.88
F	Insemination	94	2.54	36.29	5:30	145.76
F	1st lact. calving	3	4.00	17.04	5:13	19.33
F	Treatment	*	*	*	*	*
G	Medium yield	254	1.59	28.31	04:14	145.68
G	Low yield	249	1.83	27.10	03:57	245.37
G	Sick cows	47	3.11	25.71	04:10	194.49
G	Sick cows	113	2.23	22.02	03:29	36.14
H	Mastitis	51	2.29	28.84	05:25	222.37
H	High yield	93	2.07	30.80	05:46	253.41
H	High yield	77	2.30	21.32	04:42	309.94
H	Sick	21	2.57	25.55	05:05	190.43
H	Low yield	110	2.33	15.54	04:01	374.46
H	30 DIM ≥	127	1.15	31.45	05:50	143.83
H	Colostrum	16	2.38	**	**	14.31
H	20 DIM ≥	115	2.72	35.08	04:50	178.92
H	From group 14	50	2.34	37.62	05:23	160.78
H	Newly calved	79	2.38	35.83	06:27	28.52
H	From group 14	123	2.74	37.03	05:13	147.84
H	Dry cows	25	2.20	11.04	03:23	348.00
I	High yield	382	2.36	33.68	04:19	136.74
I	Low yield	262	2.03	22.29	03:43	268.02
I	High yield *S.a.****	189	3.86	31.25	04:17	202.12
I	Low yield *S.a.****	184	3.61	20.19	03:37	291.38
I	Treatment	212	1.87	**	**	161.54
I	Mixed group	170	4.08	36.97	04:47	67.39
I	1st lactation	109	1.03	27.47	03:50	97.52

* Cows in this group belong to any of the other groups but were physically milked in a separate group
**Missing data for cow groups with bucket milking
*** *Staphylococcus aureus (S.a)*

Appendix 5

Table 1. Mean individual cow duration (±SE) in seconds for entry (n=360 cows/farm) and exit (n=240 cows/farm) for each farm A-I with the PR2100 (n=5 farms) and the PR3100HD (n=4 farms)

Farm	**Entry**	**Exit**
PR2100		
A	6.1(0.11)	22.8 (0.85)
B	5.4 (0.09)	18.0 (0.75)
C	5.0 (0.09)	20.6 (0.80)
D	5.7 (0.11)	18.0 (0.65)
E	5.0 (0.10)	19.7 (0.80)
PR3100HD		
F	5.2 (0.07)	11.3 (0.34)
G	5.4 (0.12)	14.8 (0.58)
H	5.2 (0.07)	12.5 (0.30)
I	4.8 (0.07)	14.6 (0.50)

Appendix 6

Table 1. Total number of empty bails, cows on second rotary lap and times the rotary was run backwards during entry (n=360 observations/farm) and exit (n=240 observations/farm) at each farm and times the staff was herding the cows at exit for the two different rotary models PR2100 (n=5 farms) and PR3100 HD (n=4 farms)

Farm	**Entry**			**Exit**			
PR2100	Empty bail	Second lap	Back rotary	Empty bail	Second lap	Back rotary	Staff herding
A	4	0	1	5	0	1	1
B	18	2	1	15	1	5	0
C	7	3	2	5	0	0	8
D	9	9	1	13	2	5	10
E	2	22	2	7	9	11	2
PR3100H							
F	7	1	0	5	1	0	1
G	11	29	0	0	19	0	9
H	4	0	0	1	0	0	1
I	15	0	1	1	0	2	1

Appendix 7

Table 1. Total number of recordings of behaviours during entry (n= 360) at each farm (A-I) and the two different rotary models PR2100 (2100, n=5) and PR3100 HD (3100, n=4)

Farm	Voluntary	Sniff	Push	Head push	Ruminate	Rub	Lick	Chin rest	Eliminate	Slip
PR2100										
A	347	175	0	0	27	1	0	2	1	1
B	352	150	0	1	57	3	1	0	0	0
C	350	276	3	3	18	5	0	1	1	0
D	348	153	1	2	77	2	2	0	0	0
E	354	255	1	7	3	1	2	1	0	0
PR3100HD										
F	353	136	7	0	49	3	1	0	1	0
G	290	45	69	4	3	0	0	0	4	3
H	348	283	12	0	25	0	1	0	0	1
I	345	128	14	7	5	0	0	0	0	1

Appendix 8

Table 1. Total number of recordings for behaviours during exit (n= 240) at each farm (A-I) and the two different rotary models PR2100 (2100, n=5) and PR3100HD (3100, n=4)

Farm	**Voluntary**	**Sniff**	**Bump**	**Stand**	**Push**	**Ruminate**	**Eliminate**	**Lick self**	**Throw head**	**Rub**	**Slip**	**Limp**
PR2100												
A	240	36	145	135	78	110	3	0	0	0	1	0
B	237	30	86	82	36	55	13	1	0	4	1	0
C	239	23	95	180	26	6	1	64	49	1	0	0
D	239	11	118	99	40	81	1	1	0	1	0	0
E	225	24	102	104	41	33	1	0	6	0	1	4
PR3100HD												
F	239	7	63	51	60	78	1	0	0	0	1	2
G	220	25	64	92	36	62	6	0	1	4	1	0
H	238	19	60	44	25	77	4	0	0	0	2	4
I	240	7	102	99	43	102	1	1	0	0	0	0

Appendix 9

Table 1. Frequency of rotary stops, rotary stop duration, use of tool and hand during entry for each of the farms A-I (n=360 observations/farms) in the PR2100 and PR3100HD

Farm	**Rotary stop**		**Stop duration**			**Tool**		**Hand**	
	Cow	Other	<30 s	31-60 s	>60 s	Towel	Stick	Beside	Behind
PR2100									
A	19	79	57	25	18	0	1	12	0
B	7	19	21	2	3	0	0	9	0
C	12	29	26	9	6	0	2	4	0
D	13	22	29	3	3	1	1	7	2
E	12	69	61	11	9	0	0	3	1
PR3100HD									
F	0	5	3	1	1	0	0	0	1
G	11	18	17	3	9	1	0	0	1
H	1	19	8	5	7	0	0	0	0
I	1	13	8	3	3	0	0	1	0

Appendix 10

Table 1. Frequency of rotary stops, rotary stop duration, use of tool and hand during exit for each of the farms A-I (n=240 observations/farms) in the PR2100 and PR3100HD

Farm	**Rotary stop**		**Stop duration**			**Tool**		**Hand**	
	Cow	Other	<30 s	31-60 s	>60 s	Stick	Water	Beside	Behind
PR2100									
A	0	98	54	35	9	0	0	0	0
B	3	14	8	7	2	0	0	0	3
C	2	29	23	4	4	0	0	0	0
D	4	24	25	2	0	0	1	0	0
E	14	65	63	14	2	3	0	0	0
PR3100HD									
F	2	5	7	0	0	0	0	0	0
G	0	25	17	3	5	1	1	3	0
H	0	12	8	1	2	0	0	0	0
I	2	11	10	3	0	0	0	0	0

Vid **Institutionen för husdjurens miljö och hälsa** finns tre publikationsserier:

* **Avhandlingar:** Här publiceras masters- och licentiatavhandlingar

* **Rapporter:** Här publiceras olika typer av vetenskapliga rapporter från institutionen.

* **Studentarbeten:** Här publiceras olika typer av studentarbeten, bl.a. examensarbeten, vanligtvis omfattande 7,5-30 hp. Studentarbeten ingår som en obligatorisk del i olika program och syftar till att under handledning ge den studerande träning i att självständigt och på ett vetenskapligt sätt lösa en uppgift. Arbetenas innehåll, resultat och slutsatser bör således bedömas mot denna bakgrund.

Vill du veta mer om institutionens publikationer kan du hitta det här: www.slu.se/husdjurmiljohalsa

DISTRIBUTION:
Sveriges lantbruksuniversitet
Fakulteten för veterinärmedicin och husdjursvetenskap
Institutionen för husdjurens miljö och hälsa
Box 234
532 23 Skara
Tel 0511–67000
E-post: hmh@slu.se
Hemsida: www.slu.se/husdjurmiljohalsa

Swedish University of Agricultural Sciences
Faculty of Veterinary Medicine and Animal Science
Department of Animal Environment and Health
P.O.B. 234
SE-532 23 Skara, Sweden
Phone: +46 (0)511 67000
E-mail: hmh@slu.se
Homepage: www.slu.se/animalenvironmenthealth