Optimising Cow Traffic in Automatic Milking Systems

- with Emphasis on Feeding Patterns, Cow Welfare and Productivity

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Abstract

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This thesis comprises the results from three separate studies performed in the experimental automatic milking system at Kungsängen Research Centre, Swedish University of Agricultural Sciences, Uppsala, Sweden. In the first study, 30 high-yielding cows in early lactation were subjected to two different degrees of controlled cow traffic, and the effects on milk yield, dry matter intake, feeding patterns and voluntary visits to the milking unit and the control gates were measured. A model of mixed distributions for estimations of biologically relevant meal criteria from registrations in roughage stations was also evaluated. In the second study, the behaviour of 24 cows after they had been redirected in control gates was observed, and the cause of long redirection times from gates until they showed up in the milking unit was examined. In the third study, 9 cows were subjected to three different cow traffic systems in a carry-over design and the effects on cortisol concentrations in milk and ruminating patterns were studied.

The studies showed that milking frequency and thereby milk production can be altered by different time settings in the control gates without limiting the daily feed intake of the cows. A high degree of guidance provokes social effects in the queue in front of the milking unit and in the feeding areas. It also makes it difficult for the cows to follow their natural feeding patterns. Judging from measurements of milk cortisol concentrations, controlled cow traffic was not stressful for the cows. Cows initiated meals with short intervals, which offered many opportunities to milk them. But the queue in front of the milking unit caused long redirection times, and the control gates failed to guide cows to high milking frequencies. Individual differences in feeding patterns and how cows respond to redirections in the control gates suggest that the control gates should be making decisions on an individual level.

Keywords: Automatic milking, feeding patterns, cow traffic, individual management, milking frequency, cow welfare, stress, cortisol, social rank.

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"It is a job that is never started that takes the longest to finish"

J.R.R. Tolkien

To Elle and Sparven

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Paper II. Melin, M., K. Svennersten-Sjaunja and H. Wiktorsson. 2005. Feeding Patterns and Performance of Cows in Controlled Cow Traffic in Automatic Milking Systems. *Journal of Dairy Science (Accepted for publication).*

Paper III. Melin, M., G.G.N. Hermans, G. Pettersson and H. Wiktorsson. 2005. 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 (Accepted for publication).*

Paper IV. Melin., M., G. Pettersson, K. Svennersten-Sjaunja, and H. Wiktorsson. 2005. Chewing Activities and Cortisol in Milk of Dairy Cows in Automatic Milking Systems with Different Degrees of Controlled Cow Traffic. (*Manuscript*).

List of abbreviations and terminology

AM Automatic milking
CG Control gates
DM Dry matter
DMI Dry matter intake
ECM Energy corrected milk
FR Free cow traffic routine
FO Forced cow traffic routine
MU Milking unit
PP Postpartum
SE Selective cow traffic routine.
× Times daily

The terminology used in this thesis; brief descriptions of terms are given in this table. More elaborate descriptions can be found in the presented papers (Appendix).

Term	Swedish term	Description
Automatic milking system	Automatiskt mjölkningssytem	A system that integrates feeding, milking, cow traffic and to a part cow surveillance, based on the cows' voluntary visits to barn facilities.
Control gate	Kontrollgrind	A unit (gate) for cow traffic control.
Controlled cow traffic	Kontrollerad kotrafik	When access to a resource (feed) to a varying degree is limited in order to redirect cows to the milking unit (selective and forced cow traffic).
Feeding visit	Foderbesök	A registration in a roughage or a concentrate station
Forced cow traffic	Styrd kotrafik	When the only way to reach a resource (feed) is through the milking unit (Controlled cow traffic).
Free cow traffic	Fri kotrafik	When cows can move freely between barn facilities, i.e. no attempt to control the cow traffic with control gates is made.
Meal	Måltid	A number of feeding visits that is clustered in time (see Paper I).
Milking compartment	Mjölkningsavdelning	Comprises a milking unit and the waiting area in front of the milking unit.
Meal criteria	Måltidskriterium	The longest interval between two visits in feeding stations that is considered to not to separate two meals.
Milking unit	Mjölkningsenhet / Mjölkningsstation	Unit for udder preparation and milking.
Selective cow traffic	Selekterad kotrafik	When cows have access to a resource (feed) a limited amount of time after milking (Controlled cow traffic).
Redirection	Styrning/nekning	When a cow makes an attempt to enter the feeding area through a control gate but is redirected to the waiting area / milking unit.
Redirection time	Styrningstid /nekningstid	The time elapsed from a redirection in a control gate until the cow reports in the milking unit (Figure 2).
Return time	Återbesökstid	The time elapsed from a milking until the cow returns for initiating a non-milking related meal (Figure 2).
Waiting area	Väntyta	The area in front of the milking unit, can either be open (e.g. in the present studies) or closed (e.g. Hermans et al., 2003).

Introduction

The first commercial automatic milking (**AM**) system was installed at a dairy farm in the Netherlands in 1992, and since then the number of farms in the world using an AM system had increased to about 2200 by the end of 2003 (Koning and Rodenburg, 2004). The initial drive for the development of an AM system was increasing costs of inputs and labour and decreasing milk prices. This forced the farmers to increase production per invested man hour. In Sweden, the first AM system was introduced on a commercial farm in 1997. Since then, about 400 systems have been installed on Swedish farms. In Scandinavian countries the dairy cows are housed indoors during normally 8 to 10 months of the year. Substantial investment in barns and feeding equipment requires a high return in milk for each individual cow (Samuelsson, 2001). The high costs of milk production in Sweden were recently brought up by the Swedish Dairy Association (2003), where it was concluded that feed prices were higher than in other European countries. The expectation of increased milk yields and labour savings in AM systems is of course promising for farmers in order to deal with the harsh economical situation. An additional reason for the fast development of AM systems in Sweden is the favourable herd structure, where a large proportion of farms have about the number of cows required for keeping one unit busy (Swedish Dairy Association, 2003). Other important arguments for farmers in favour of making an investment in AM systems are reduced physical labour, more flexible working hours and increased milk yields (Hogeveen *et al.,* 2004).

There are high expectations of the AM system in the management of dairy cows. AM systems could take a role as a tool to control milk production, and play an important role in strategies for the management of dairy cows. A high milking frequency in early lactation generates a cell proliferation of milk secretory cells (Wilde *et al.,* 1986) and this has lasting effects on milk yield in mid and late lactation (Bar-Peled *et al.*, 1995). This may be used in management strategies aiming for prolonged lactations (Österman and Bertilsson, 2003). In early lactation, for cows going through a period of negative energy balance, it could be of interest to temporarily limit the milk yield by reducing the milking frequency until the feed intake and nutritional status is resumed (Rémond *et al.* 1992). Successful guidance of cows towards target milking frequencies is an essential part in an individual approach to management in AM-systems (Devir and Maltz, 1995). However, recent results from farm surveys showed disappointing results regarding the expected milk yield increase after AM systems had been introduced, which may suggest problems when implementing fully automatic milking routines on farms (Poelarends et al, 2004). Cows not reporting to the milking unit regularly is a major reason for culling (Østergaard *et al.,* 2002), which indicates sub-optimal cow traffic on the farms. The lack of the expected milk yield increase is a major impediment in further developing the AM system to a management tool for production control, and possible reasons for it must be evaluated under experimental conditions, especially since it contradicts results from controlled studies (Svennersten-Sjaunja *et al.* 2000).

The introduction of AM systems not only brought on a totally new milking regime with voluntary visits to the milking unit and possibilities of quarter milking, it also involved a new system for feeding the cows. The design of an AM system must allow for a high feed intake and let the cows feed whenever they want to. Concerns that controlled cow traffic, and in particular forced cow traffic, might prohibit the cows from performing their natural feeding pattern, which in turn might limit their feed intake and decrease production have been raised by several studies (Ketelaar-deLauwere and Ipema, 2000; Harms *et al.,* 2002; Hopster *et al.,* 2002a b; Luther *et al.*, 2002). The effect on feed intake of different cow traffic routines needs to be examined.

The AM system integrates essential parts of management, such as feeding and milking. The term cow traffic describes the movements of cows between barn facilities to perform these activities, and problems in the AM barn can therefore often be related to a disturbed cow traffic. In controlled cow traffic, the cow is allowed to feed of her own accord and is milked en route to the feeding area. The motivation to feed is strong in animals and the feeding pattern of the cow can be seen as the drive in cow traffic, and any change in management that inflicts a change in the feeding patterns of the cows will affect the voluntary visits to the milking unit. Knowledge of feeding patterns of dairy cows should form a basis for the improvements of existing cow traffic systems and the design of new systems. However, existing knowledge about feeding patterns is related to tied-up dairy cows (Metz, 1975; Dado and Allen, 1993) and cows held in ordinary loose-housing systems (Tolkamp *et al.,* 2000; Tolkamp *et al.,* 2002), but little is known about feeding patterns in AM-systems.

In the dairy cow and other animals, feeding is in distinct meals, and changes in feed intake result from modification of the size of meals and/or the interval between them (Faverdin et al., 1995). Analysis of feeding patterns has been found to be appropriate when studying the regulation of feed intake in the short term, and has given insights into how feeding is affected by feed quality (Tolkamp *et al.,* 2002), social environment (Nielsen, 1999) and different management practices (Albright, 1993). With computerized feeders, feeding visits can easily be recorded, which allows for detailed studies of feeding patterns on an individual level over the whole lactation period. Earlier studies of feeding patterns in AM-systems have used definitions of meals that have either been arbitrary or based on the assumption that meals are randomly distributed in time (Morita *et al.,* 1996; Harms *et al.,* 2002). Tolkamp *et al.* (1998) showed that the distribution of meals in time was dependent on satiety mechanisms, and therefore the view of randomness was criticized as lacking biological relevance. A proper definition of a meal is critical for the interpretation of feeding patterns, and there is a need to evaluate existing models for data obtained in AM systems.

Common strategic goals in the AM herds are maximum production, labour savings, maximal economic output or any combination of these. However, the welfare of the dairy cow must not be neglected in the strategic planning. It is sometimes argued that allowing the cow to have maximum control of her daily activities, such as milking and feeding, improves animal welfare (Hurnik, 1992; Prescott *et al.,* 1998). In this respect, AM systems where cows to a high degree feed and visit the milking unit of their own accord could lead to improved welfare. Different strategies for managing the cow traffic in automatic milking systems have been developed, and AM-systems with a high degree of controlled cow traffic result in long queuing times, especially for animals with a low social rank (Thune *et al.,* 2002). Fraser and Broom (1990) stated that any situation that results in some individual trying to feed but being excluded from the feed source is a bad one. It can be hypothesised that prohibiting the dairy cow to enter the feeding area and obliging her to enter the sometimes very crowded waiting area in front of the milking unit, may lead to frustration. It must be questioned whether controlled cow traffic in this sense is something that the cows easily can adapt to or if it can be considered as an abuse of cow welfare.

In precision agriculture the aim is to manage the basic production unit, which in the dairy herd is the individual cow. Swedish farmers have long experience of feeding the cows individually. The concept of true individual feeding of dairy cows was initiated in commercial herds in the 1980s, and since then about 50 % of the Swedish dairy cows are fed according to ratios formulated in a management tool for individual feeding. This concept has been proven to be successful with only moderate overfeeding of energy and metabolizable protein (Gustafsson and Emanuelsson, 2004). The AM system offers the possibility of using milking frequency together with individual concentrates allocation as a control of milk production. Physiological models incorporating information on cow body weight, milk production, milk composition and concentrate intakes can be combined with individual settings of milking frequency and concentrate allocation to manage the cow individually along the course of lactation (Maltz *et al.,* 1992a b; Devir *et al.,* 1997; Maltz, 1997; Maltz *et al.,* 2002). However, a prerequisite for such an individual approach to management is that the cow traffic system must enable cows to be guided to preset milking frequency aims. The possibility of an individual cow traffic approach in existing AM systems has not yet been investigated under full barn conditions.

The difference in existing cow traffic systems is wide and several variants have been evaluated and reported in the literature. When free cow traffic is applied, i.e. the cows can move freely between the barn facilities, the cows pay many visits to the feeding area but usually the number of milkings is not satisfactory. When forced cow traffic is applied, i.e. the cows can only enter the feeding area through the MU, the opposite situation to free traffic appears; more frequent milkings but an unsatisfactory number of meals per cow (Ketelaar-deLauwere *et al.,* 1998; Thune *et al.,* 2002). In addition, forced cow traffic results in long queuing times, which may have an impact on cow welfare, especially for animals with a low social rank (Thune *et al.,* 2002). As an alternative to free and forced cow traffic, there exist intermediate systems where the traffic is controlled with CGs at the entrances to the feeding area (usually referred to as selective cow traffic). In these systems, cows are either let through (gate opens) or redirected to the waiting area in front of the MU (gate remains closed). In some intermediate systems, the waiting area is closed, i.e. the cows have to enter the MU to leave the waiting area (e.g. Hermans *et al.,* 2003). In the present study, the waiting area in front of the MU was open, which gave the cows the possibility of heading towards the resting area instead of entering the MU after a redirection in a CG. This system was studied because it offered the possibility of subjecting cows to different degrees of guiding, and the open waiting area offered the cows maximum control of their daily activities.

Objectives

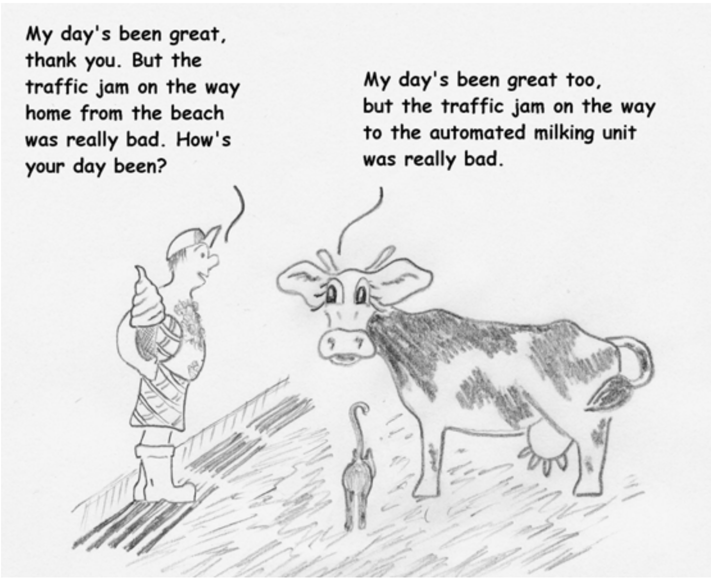
The main objectives of this thesis were:

- To find a biologically relevant definition of a meal for cows housed in an AM system with controlled cow traffic by the means of a statistical model consisting of mixtures of Gaussian and Weibull distributions.

- To study the effects of different degrees of guidance in AM systems during early and mid lactation on milk yield, dry matter intake, feeding patterns and ruminating patterns.

- To study the effects of controlled cow traffic in AM systems on the visiting patterns to the milking unit and the control gates, both on group level and on an individual cow level.

- To evaluate the effects of controlled cow traffic in AM systems on the welfare of dairy cows.



Material and methods

This research comprises three separate studies performed in the experimental AM system at Kungsängen Research Center, Swedish University of Agricultural Sciences, Uppsala in the years 2001 and 2002. Information given in this section concerns all three studies if nothing else is mentioned in the text. The studies are presented in four papers as follows:

The controlled cow traffic study

Thirty cows were subjected to two different controlled cow traffic routines from week 2 post partum (PP) to week 19 PP. The two routines aimed at guiding the cows to either a high or a low average milking frequency by limiting the time the cows could access the feeding areas via the control gates. In paper I, the feeding visits to roughage and concentrate stations were modeled in mixtures of Weibull and Gaussian distributions. In paper II , the effects on cow traffic and meal patterns were analysed.

The behaviour study

In this study, the behaviour of twelve cows of high social rank and twelve cows of low social rank was studied for a total of 60 min after the cows had been redirected in a control gate. This was repeated five times per cow, resulting in 120 observations in total. In addition, redirection time, return time and milking interval were extracted from the AM database. The study is presented in paper III.

The welfare study

Nine cows were subjected to three different cow traffic routines allocated on three periods in a change-over design. Milk samples were collected for measurements of cortisol concentrations, and chewing activities were recorded with strain gauge transducers (behaviour recorder). The study is presented in paper **IV**.

Animals

The dairy cows were of the Swedish Red and White breed. The cows that participated in the three studies were early- or mid-lactating. The number of cows housed in the barn during the studies was kept as high as possible in order to reflect the real on-farm situation. Approximately one third of the cows were primiparous and the remaining were of parities two to seven. Average milk production of the research herd in the studied years was 9500 kg energy corrected milk (**ECM**) (Sjaunja *et al.*, 1990) with 4.5 % fat and 3.4 % protein on average. The average bulk somatic cell count of the herd during the study period was 102,000 (SD 53,000) cells per ml/ milk.

The experimental AM system

The barn was a loose-housing system including a resting area, two separate feeding areas and a milking compartment. From the resting area the cows could enter either of the two feeding areas through one of the two control gates (**CG**) or through the milking unit (**MU**). Barn layout is presented in Figure 1. The cows could leave the feeding areas through self-closing exit gates.

The milking area consisted of one milking unit (DeLaval VMS™) and a 40 square meter open waiting area in front of the unit entrance. In the milking unit, the cows were milked on the condition of having permission to be milked. If they did not have permission to be milked, they were allowed to walk through the milking unit. When a cow was milked in the milking unit she was rewarded with a small amount of concentrate. The area in front of the control gates was referred to as the passage area. The milking unit was accessible at all times during the day, except at times for system cleaning and milk handling. System cleaning occurred during 30 min at 9 a.m. and 1 p.m., and during 60 min at 2 a.m. During nights there were full illumination in all areas of the barn.

In each of the two feeding areas there were ten roughage feeding stations (Bio-control A/S, Norway) and one concentrate feeding station (DeLaval AB, Sweden) one mineral bucket, one salt lick and one water bowl. Another four water bowls were placed in the resting area. When a cow entered the station for feeding roughage, the front bar lowered to give access to feed in the trough. When a cow withdrew from the station, the bar rose to prevent unauthorised feed consumption by other cows. Roughage was allocated 5 times a day in such amounts that troughs were never empty.

The concentrate feeding stations consisted of a concentrate dispenser, an antenna for cow identification and an automatic gate. This gate was automatically lowered behind a cow that entered the feeding stations to protect from batting from barn mates while feeding. The gate stayed down as long as the cow kept her head in the feed dispenser's trough on condition that she had permission to eat concentrate. The available ration for concentrate that a cow was allowed to have was increased through time. A maximum amount of concentrate was dispensed on the condition that the amount of concentrate a cow was qualified for was more than 300 grams. In case not all available concentrate was consumed at 12 PM, a certain amount of the remaining concentrate was made available the following day.

Data acquisition and definitions

The measures that were registered on-line and stored in the AM database are presented in Table 1. Data from the feeding stations were used to determine the dominance position of each cow in the herd (Olofsson, 2000). On basis of this dominance value, the cows were classified to be either of high or low social rank. Redirection time, milking interval and return time were extracted from database registrations (Figure 2). Redirection time was defined as the time elapsed from when a cow was redirected in the CG, until she entered the MU. Milking interval

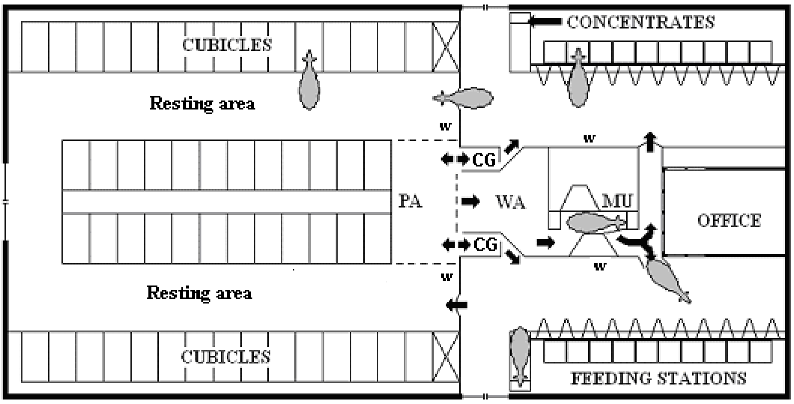


Figure 1. Layout of the AM system. Abbreviations: CG= control gate, MU= milking unit, PA= passage area, WA= waiting area, w=water bowl.

was defined as the interval between two milkings. Return time was defined as the elapsed time from a milking to the first attempt to make a non-milking related feeding meal by register in a control gate; (i.e. the elapsed time for the following sequence of incidents: milking→ milking-related meal → end of milking-related meal → passage/redirection in CG). Individually estimated meal criteria were used to decide whether the cows returned to begin a new meal or to resume an on-going meal.

Table 1. On-line measures extracted from the AM database for the analyses in the study.

Measure	Data logged at	Comment
Cow identity	CG, CS, MU, RS, WB	
Entrance time	CG, CS, MU, RS, WB	Min visit interval in WB= 1 sec, RS= 3 sec
Exit time	CS, MU, RS, WB	Registered when: cow raised her hed to leave the CS; exit gate closed in MU; front bar raised in RS
Amount of concentrate	CS, MU	Dispensed if cow had: milking permission in MU; allowed amount in CS
Milk yield	MU	
Milking success	MU	
Gate decision	CG	Decisions: gate opened / gate remained closed
Cow body weight	CS	
Trough weight at entrance	RS	
Trough weight at exit	RS	
Water flow	WB	

Abbreviations: CG=control gates, CS=concentrate feeding stations, MU=milking unit, RS=roughage feeding station and WB=water bowls.

In paper **IV**, a queue variable was introduced that was based on the assumption that if a cow entered the milking unit more than two minutes after the previous cow had left, the waiting area had been empty from queuing cows at the time of entrance. If the time was shorter than two minutes, it was assumed that the cow had been in a queue; waiting for system cleaning was not counted. The queue variable took either of two values: cow in a queue/cow not in a queue. In addition, a waiting variable was introduced that was assumed to reflect the queuing time in front of the milking unit. This was the time from the first registration in a water bowl or in the control gates within the time window of one hour before a milking event. The waiting variable took a value between 0 and 60 min.

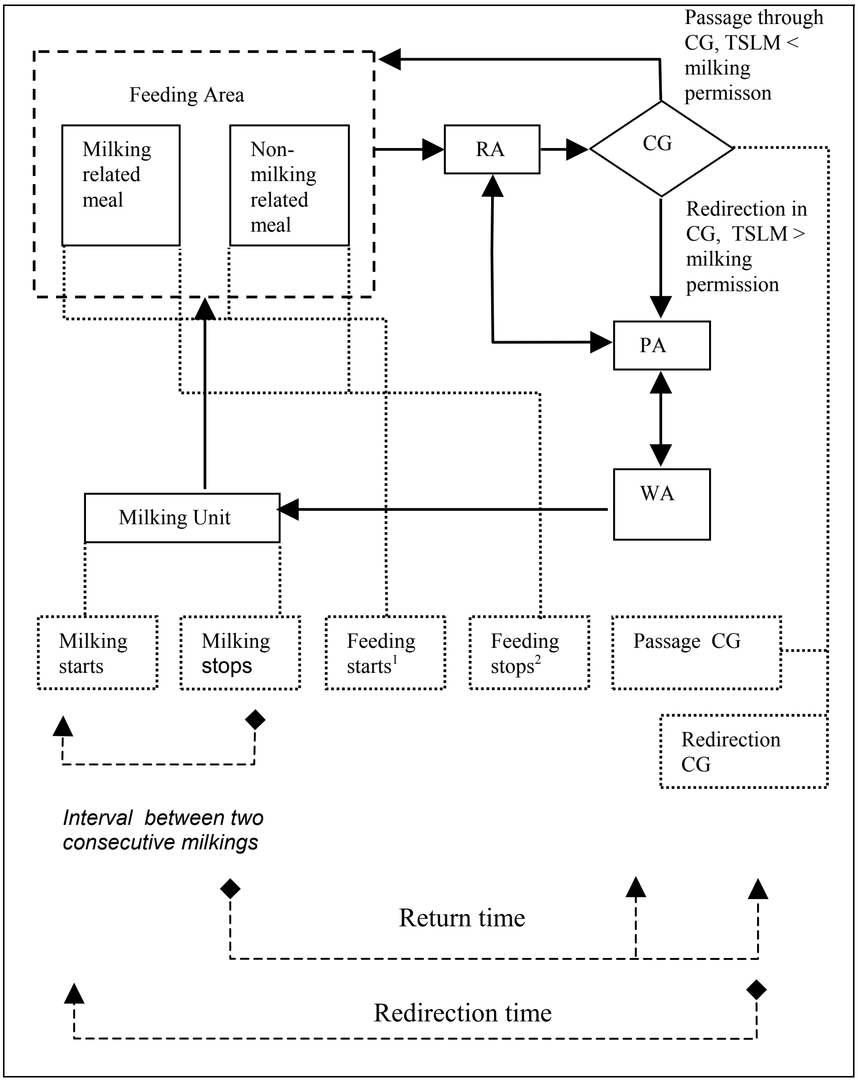


Figure 2. A flow chart of the cow traffic system in the study. Dotted lines indicate events that were extracted from the database and used for calculations of three time measures: milking interval, return time and redirection time. The broken arrows indicate what events were used for the three time measures, respectively; the time measures were calculated as the elapsed time from event ♦ to event ▲. [1] The start of a meal=the first visit in a feeding station. [2] The end of a meal=the end of the last feeding visit during a meal.
Abbreviations: CG = control gate, FA = feeding area, MU = milking unit, PA = passage area, RA = resting area, WA = waiting area, TSLM=time since last feeding.

Sampling and analysis of milk and feeds

Once a week milk samples were collected from each milking during a 24-hour period. Milk samples were analyzed for fat, protein and lactose with mid-infrared spectroscopy (Milkoscan 5000, Foss Electric, Denmark).

Cortisol concentration in milk was measured in paper **IV**. All milk samples were stored frozen until extraction of free cortisol. Milk cortisol was measured using the Coat-A-Count® radioimmunoassay (Diagnostics Product Corporation, Los Angeles, CA, USA). Before cortisol was analysed, the free cortisol fraction was extracted with acetone (GR, Merck, Darmstadt, Germany) and petroleum benzene (GR, boiling range 40-60 °C, Merck, Darmstadt, Germany) with a recovery of 87.3%.

The concentrate contained (as percentage of total DM) 30% barley, 20% oats, 16% rapeseed meal, 14% soybean meal, 14% beet pulp, 4% wheat bran and 2% mineral mix. The silage consisted of a mix of fescue, timothy and a small proportion of red clover. A representative sample was taken once a week for analysis of the quality of the silage. Neutral detergent fiber (NDF) was analyzed by the oven method (Chai and Udén, 1998). Metabolizable energy of the silage and hay was determined from the 96 hrs digestible organic matter (Lindgren, 1979). The metabolizable energy in concentrate was determined from the crude analysis and standard digestibility coefficients and energy values according to the Swedish feeding standard (Spörndly, 2003). The crude protein content of feed was determined by analyzing Kjeldahl nitrogen.

Recording chewing activity

The chewing activity was recorded in the welfare study (paper **IV**). The cows' jaw movements were recorded using an IGER behaviour recorder (Ultrasound advice, London, U.K.), described by Rutter *et al.* (1997). It consisted mainly of a nose-band that sensed the jaw movements connected to a microcomputer (Figure 3). The jaw movement amplitude data were recorded at 20 Hz. Data files were analyzed in the software GRAZE® version 0.8 (Ultrasound Advice, London, U.K.). This program displayed a plot of the jaw movement amplitude registered by the noseband sensor (Figure 3). Individual jaw movements were identified using different amplitude and frequency criteria specified by the user. Bouts of jaw movements were discriminated and classified as either feeding roughage, feeding concentrate or ruminating. Tallies of different classes of jaw movements together with tallies of chews during feeding and ruminating, and tallies of boli regurgitated during rumination were transferred to SAS 8.02 for analysis (SAS, 1999).

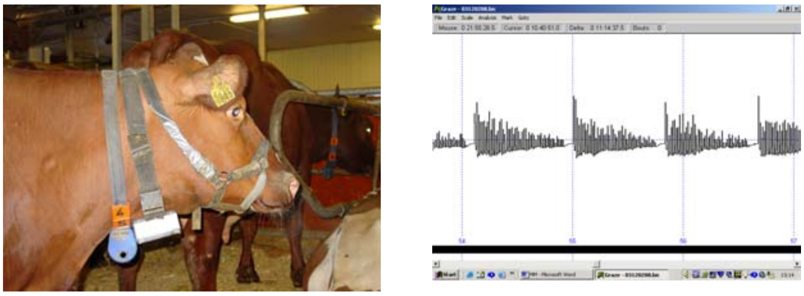


Figure 3. Noseband sensor, head collar and recorder as fitted to a cow (left), and the jaw movement amplitudes during rumination as displayed in GRAZE® 0.8 (right).

Statistical methods

Variance analysis was performed on all data using procedure GLM (paper **I**) and procedure MIXED (paper **II-IV**) in SAS 8.02 (SAS, 1999). Statistical models are described in each paper. A feeding visit was a visit to either a roughage or a concentrate station. Feeding intervals were LN-transformed and mixtures of Gaussian (Normal) and Weibull distributions were fitted to individual data. The estimation of model parameters was handled by the maximum likelihood method described by Everitt and Dunn (2001), and a program for the iterative process was written in the IML procedure of SAS 8.02 (SAS, 1999). For each population the mean $\mu_{i,}$ the variance $\sigma^2_{i,}$ and the proportion parameter p_i were estimated. The mean (given in original time) of the Normal distribution was transformed from the estimated model parameters as: $e^{\alpha+\sigma^2/2}$ (Johnson, 2000). For models including a Weibull distribution, the scale parameter α and the shape parameter β were estimated. From these two parameters, the expectation (μ_i) was derived as: $\alpha\times\Gamma(1+1/\beta)$ (Johnson, 2000) where Γ denotes the gamma function. The definitions of the meal and bout criteria were points where two population curves crossed.

Methodological comments

Estimation of social rank

With dominance relationships, the cows can predict the outcome of an aggressive interaction, which usually is advantageous both for cows of low and high social rank. The dominance position of a cow kept in a group is related to the chances of obtaining limited resources. Dominance relationships have been shown to be very stable over time (Wierenga, 1990), and it is not likely that the dominance values changed through time during the present studies. In the behaviour study and the welfare study (paper **III** and **IV**) the dominance positions of the experimental cows were assessed by studying the succession order in roughage stations. When a cow replaced another cow within 1 minute after the previous cow had left, she gained 1 score in a dominance matrix. A cow was consiedered dominant in all relationships where she had at least twice as many scores as the opponent cow. Rutter *et al.* (1987) showed a high correlation between the visually observed social rank and the social rank that was estimated from automatically obtained records of visits to roughage stations. In the present studies, the social rank order was used to explain social competition at the waiting area in front of the milking unit. Ketelaar-deLauwere *et al.* (1996) found that cows of high social rank entered the MU more often without spending time in a queue. Thune *et al.* (2002) found that cows of low social rank had a longer total daily waiting time in front of the MU compared to cows of high social rank. Olofsson (2000) found a high correlation between the social rank position assessed from data obtained in roughage stations and the succession order in the MU. Based on this, there appear to be good reasons to believe that the methods for estimating social rank in the behaviour study and the welfare study reflect the social competition at the waiting area.

Assessment of stress

Assessment of adrenocortical activity has been used as an indication of physical and psychological stress in dairy cattle in several studies. Cortisol measurements have been obtained both in plasma (Bremel and Gangwer, 1978), saliva (Hernández *et al.,* 2004), faeces (Lexer *et al.,* 2004) and in milk (Bremel and Gangwer*,* 1978). Measurement of milk cortisol concentration is a non-invasive and animal-friendly method. The samples are easily obtained and elevated concentrations due to chronic stress or due to exposure to an acute stressor 30 min before sampling can be identified (Fox *et al.,* 1981; Termeulen *et al.,* 1981). The hypothalamic-pituitary-adrenal (HPA)-axis is not the only physiological system that responds when an animal is exposed to a stressor. Both the sympathetic nervous system and behaviour are changed, and can be used as measures related to the stress response. Because the response to a stressor is specific, it is generally recommended that several indicators to be evaluated when assessing the level of stress in an animal. In the welfare study (paper **IV**), we intended to use telemetric heart rate measurements for assessment of sympathetic activation. However, because of severe technical problems with this equipment, the data produced was not reliable, and therefore discarded. If more than one measure of stress response had been used in the welfare study, the hypothesis that controlled cow traffic causes stress in dairy cows could have been tested with a higher reliability.

Assumptions of independence

The analysis of variance (ANOVA) in general requires the data to be independent. Dairy cows held in a group interact socially and the assumption of independence can therefore be questioned. If a behaviour that is expected to occur in synchrony among cows is treated as being independent, this could lead to pseudo-replication. In such a case, it would be recommended to analyse the results on the basis of group means. However, if a measure is not correlated between individual cows within a group, such a test would lead to low degrees of freedom and an increased risk of Type II errors. This discussion originated from the observation that dairy cows held in a group synchronised their grazing behaviour more than could be expected by chance and the use of individuals as replicates in grazing experiments could therefore not be motivated. For a broader discussion on this matter see (Philips, 1998; Rook, 1999; Iason and Elston, 2002). It may not be possible to confound the analysis of feeding patterns of dairy cows held in AM systems by non-independence by social facilitation among cows. Iason and Elston (2002) suggested that although behaviour is synchronized in time, the measures reflecting feeding patterns, such as meal times, are not necessarily non-independent. The synchronised feeding behaviour that often is observed in AM systems is usually related to human intervention and feed allocation, and the role of social facilitation on feeding behaviour is therefore not clear. In addition, because of the restrictions in the access to feeding areas that are introduced in controlled cow traffic, it is likely that social facilitation is, to some extent, prohibited. The fact that feeding was spread over the 24 hrs is an indication of this (paper **IV**). The fact that we identified social effects on measures related to feeding patterns and redirection time (paper **III** and **IV**) is actually proof that cows in a herd do not act independently. However, social competition for a barn facility will cause negative correlations between individual observations, which leads to a more conservative test (Iason and Elston, 2002).

Results

The controlled cow traffic study

Paper I

This paper describes the analysis of feeding visit intervals, using a mixture of Gaussian and Weibull distributions. During the experiment a total of 83,249 feeding intervals were extracted from the AM database. The analysis revealed the existence of two separate populations of intervals: short intervals between feeding visits within a meal, and longer intervals separating two meals. Clear evidence of a third population of intervals was found for 16 of the cows in the study. Of these 16 cows, 9 were primiparous, and 7 were multiparous. The third population was a result of cows pausing in their feeding to visit the water bowls (feeding → drinking → feeding), or of the cows queueing in front of the concentrate feeding station (roughage/concentrate → concentrate).

Means of individually estimated meal criteria ranged from 39.9 min to 55.3 min for different models, and means of estimated inter-meal intervals ranged from 211 to 233 min. Using a Weibull distribution for the population of inter-meal intervals increased the fit in 20 of the individual data sets, and somewhat shorter meal criteria were estimated. The confidence interval was only between 3.1 and 7.0% of the estimated meal criteria for different models. The use of a 3-population model instead of a 2-population model had little effect on the measured feeding pattern for cows having clear evidence of 3 populations in their distribution. The predicted starting probabilities of all 4 models tested reflected the observed starting probabilities well up to approximately 180 min. After that, the models with a Gaussian distribution for the population of inter-meal intervals predicted decreasing starting probabilities when the time since last meal increased. In 28 of the 30 cows, drinking data showed clear evidence of 3 populations, and the model with three Gaussians always had a better fit than the model with two Gaussians and one Weibull.

For all parameters estimated with a 2-population model on feeding data, >95% of the random error term was explained by variation between individual cows, leaving a small part to be explained by variation within individual cows.

Paper II

This paper describes the effects on meal patterns, cow traffic, dry matter intake and production when cows were subjected to either a high degree of guiding (G_{4-8}) or a low degree of guiding (G_{8-4}). The cow traffic routines were kept from week 5 to week 16 PP (periods one and two), and switched between groups in weeks 17 to 19 (period three). In periods one and two, the G_{4-8} cows were milked 3.2× and the G_{8-4} cows were milked 2.3×. The range of individual means of milking frequency in period one and two was 2.5 to 3.9 milkings per d for the G_{4-8} cows and 1.6 to 2.6 milkings per d for the G_{8-4} cows. The G_{4-8} cows produced 8.7 % more milk than G_{8-4} did in period one ($P<0.1$) and 10.6 % more milk than G_{8-4} did in period two. When measured in kg ECM the G_{4-8} cows tended to produce 8.9 % more milk than the G_{8-4} cows in period two ($P<0.1$).

In period one and period two, cows in the G_{4-8} fed in fewer meals per day than the G_{8-4} cows did, and had longer meals than the cows in the G_{8-4} had. There was no significant difference in total dry matter intake between cow traffic routines. The G_{4-8} cows had redirection times shorter than one hour in 48% of the observations, and the corresponding figure for the G_{8-4} cows was 63 %. The G_{4-8} cows had return times shorter than four hours in 85% of the observations, and the corresponding figure for G_{8-4} cows was 67 %.

The distribution of return times of four typical individual cows are depicted in Figure 4. For the G_{8-4} cows the gates closed at 480 min, which means that the cows always could achieve at least one non-milking related meal during a milking cycle (milking→milking). The individual distributions reveal that cows numbers 742 and 929 differ in their preferred return times, although they are subjected to the same cow traffic routine. For the G_{4-8} cows the gates closed at 240 min, which means that cow number 779 managed to get a non-milking related meal in roughly 94 % of her returns. The corresponding figure for cow number 707 was roughly 75 %, revealing that she often was "too late" to pass the gates for a non-milking related meal.

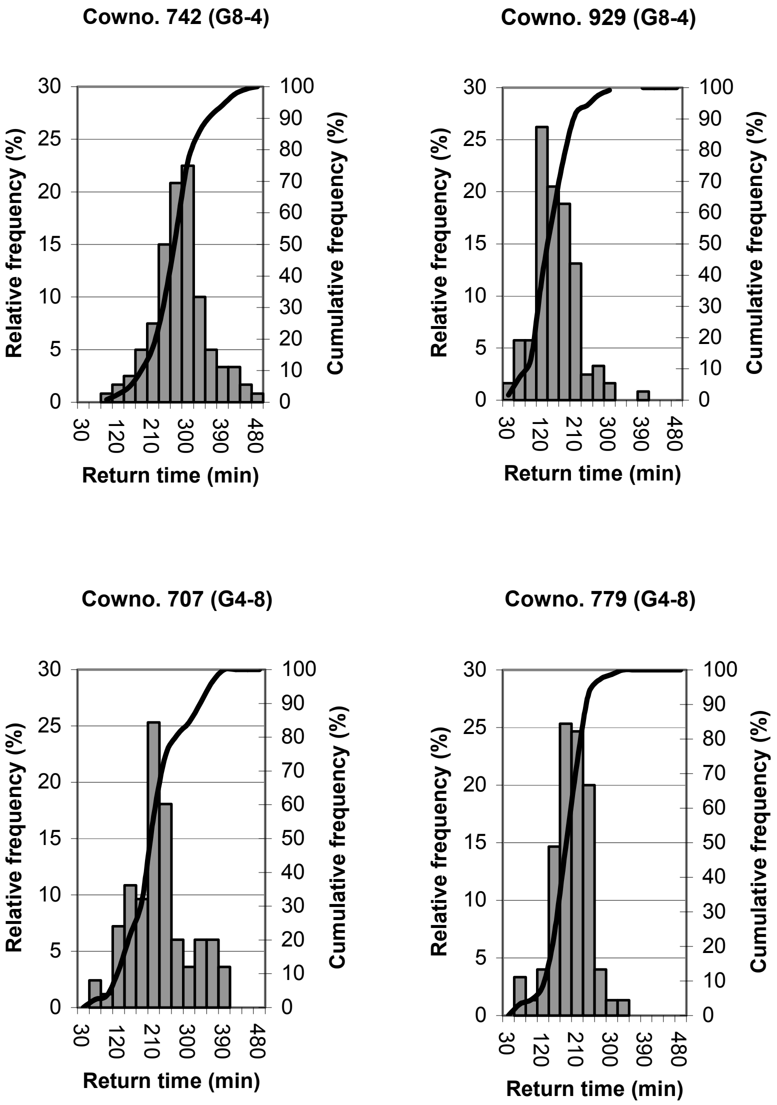


Figure 4. The distribution of return time two typical individual cows during the low milking frequency routine (MF_{8-4}) and two typical individual cows during the high milking frequency routine (G_{4-8}). The bars represent the relative frequency for class widths of 30 min. The line represents the cumulative frequency. Data is presented for period 1 and 2 (wk 5 to wk 16 in lactation).

Milking frequency and the number of passages through control gates for the primiparous cows were as high as for the multiparous cows. Primiparous cows paid more visits to the feeding stations and had longer average meal times. Cows in both milking frequency routines had gained somewhat in body condition at the end of the study, though there were no significant differences in body condition scores.

The behaviour study

Paper III

In this study the causes of long redirection times were examined. Mean redirection time was 70 ± 96 minutes for all observations. Differences between individual means were observed; the minimum individual mean was 16 ± 15 minutes and the maximum individual mean was 159 ± 165 minutes. A negative linear relationship between redirection time and time since last feeding registration was significant ($p=0.004$). In addition, a significant interaction between the time since last feeding and social rank was found. The regression coefficients were –46.6 and –48.4 for cows of low social rank and high social rank, respectively. There was also a significant negative linear relationship between redirection time and time since last milking; the regression coefficient was –19.8. In addition, an interaction between time since last feeding and time since last milking was significant.

The mean number of cows in the waiting area was 2.5 (SE:1.5) and there was a significant effect on redirection time due to the number of cows in the waiting area. Least squares means of redirection time were 15, 33, 29 and 72 minutes for 0-1, 2, 3 and 4-6 cows in the waiting area, respectively.

Cows of low social rank spent on average 20 minutes in the waiting area compared to 13 minutes for cows of high social rank. Cows of low social rank also spent less time in the resting area compared to cows of high social rank. For other time measures, there were only small differences between cows of different social rank. When comparing observations with long redirection times (>60 minutes) to observations with short redirection times (< 60 minutes), it was found that considerably more time had been spent in the resting area for observations with long redirection times; on average 2 and 32 minutes for short and long redirections times, respectively.

If redirection time was short (<60 min, n=79) then 54% of the observations had three or fewer transitions between different barn areas, 25% had 4 to 7 transitions and 21% had more than 7 transitions. Corresponding percentages for the observations with long redirections (>60 min, n=37) were 24%, 27% and 49%, respectively. In 25 of the 116 observations (22%), the cows entered the cubicles in the resting area during the observation period, and 9 of the experimental cows entered the cubicles during at least two different observation sessions, which made these cows responsible for 76% of the cubicle observations. When cows entered the cubicles they spent 40 ± 15 minutes on average there during the one-hour observation time, and the average redirection time for these observations was 185 ± 121 minutes.

The welfare study

Paper IV

In this study, the effects on chewing activities and milk cortisol concentrations due to different cow traffic routines and social rank were studied. Cows of high social rank spent significantly more time chewing while feeding, 214 minutes /d for cows of high social rank and 175 minutes /d for cows of low social rank, respectively. Cows of low social rank had faster chewing rates and spent less time chewing per kg DMI, 62.1 chews p min and 7.9 min p kg DMI for cows of low social rank and 57.6 chews p min and 9.0 min p kg DMI for cows of high social rank, respectively (P F<0.15). During the forced cow traffic routine (FO), the cows of low social rank had 382 chews p kg DMI compared to 512 chews for cows of high social rank (P F<0.12). There was no such difference during the selective cow traffic routine (SE) or during the free cow traffic routine (FR). In the FO, cows of high social rank had 3.2 non-milking related passages through the MU compared to 1.3 passages for the cows of low social rank (P t<0.1). The cows passed through the control gates during FR significantly more often than during SE and the cows tended to have more redirections in the SE compared to FO. Cows of low social rank passed the one-way gates in reverse 1.0 times /d compared to 0.01 times /d for cows of high social rank.

There was a significant effect of the cow traffic routine on milk cortisol concentrations, and least squares means for the FO was 0.43 ng/ml, for the FR 0.44 ng/ml and for the SE 0.61 ng/ml. There tended to be an effect of social rank; cows of low social rank had average milk cortisol levels at 0.46 ng/ml and cows of high social rank had average milk cortisol levels at 0.56 ng/ml. There was a significant negative relationship between the milk cortisol and the waiting variable.

Individual analysis

In order to reveal the effects of different cow traffic routines on the individual level, the temporal patterns of feeding, gate registrations and milkings were plotted for each individual. As is shown in Figure 5, all three cow traffic routines generated individual differences in the use of control gates and milking unit. Each graph represents three periods of 24 hrs for one individual cow subjected to the free (FR), selective (SE) or forced (FO) cow traffic routine. This analysis was not presented in paper **IV**.

Cow 863

In the free cow traffic routine, cow 863 used the control gates on a regular basis, and initiated meals in intervals of 2 to 3 hours (Figure 5a). Based on this pattern, this cow managed to get at least 2 meals between milkings also in the selective cow traffic routine. Actually, she made an effort to keep this interval between meals also in the forced cow traffic situation, with the result that she repeatedly was redirected to the waiting area at every attempt to pass the control gates. The

Figure 5a also shows the typical adjustment of feeding pattern of increased meal length and longer periods of non-feeding activities between meals when the degree of guiding is increased. Due to long redirection times and prolonged meal intervals there was no gain in number of daily milkings when the time limit in control gates were set at zero hrs as compared to 5 hrs in the selective routine.

Cow 832

In the free cow traffic routine, cow 832 had relatively long intervals between meals and few passages through control gates (Figure 5b). During the three studied days with free cow traffic, she rarely had more than two meals between two subsequent milkings. Theoretically, she should have been able to keep a feeding pattern with two meals (one milking related and one non-milking related) also in the selective cow traffic situation. The cause of the extremely long meal intervals in the selective cow traffic situation can only be speculated about, but the two registered redirections reveal that she has shown up too late at the control gates. It is possible that continual experience of gates that did not open when she attempted to pass taught her that control gates always are closed. It is possible that a gradual decrease of the time limits in the control gates would make the adaptation to a higher degree of controlled cow traffic easier. The temporal pattern in the selective cow traffic routine was very similar to that obtained in the forced routine for all recorded days.

Cow 960

This cow used the control gates very frequently in the free cow traffic routine (Figure 5c). The passages often coincided during the same meal, which likely is a behaviour driven by the urge to receive concentrate. This frequent use of control gates disappeared when a time limit of 5 hrs was introduced. However, she kept a regular meal pattern with meal intervals of 2 to 3 hrs. Because of short redirection times, there was a gain in number of milkings for this cow in the selective cow traffic routine. In the forced cow traffic routine, this cow kept a regular meal pattern by frequently passing the milking unit without being milked. This cow had the possibility of quickly advancing in the queue in front of the MU. For such a cow there is a possibility of a very high milking frequency without causing any extremely long feeding intervals.

Cow 870

This cow showed a very regular meal pattern with one milking-related meal and two non-milking related meals between two subsequent milking occasions (Figure 5d). In the selective cow traffic routine, the regularity in feeding was kept but the number of non-milking related meals was more often 1 rather than 2. The feeding pattern in the selective cow traffic routine was kept also in the forced cow traffic routine by passing the milking unit without being milked.

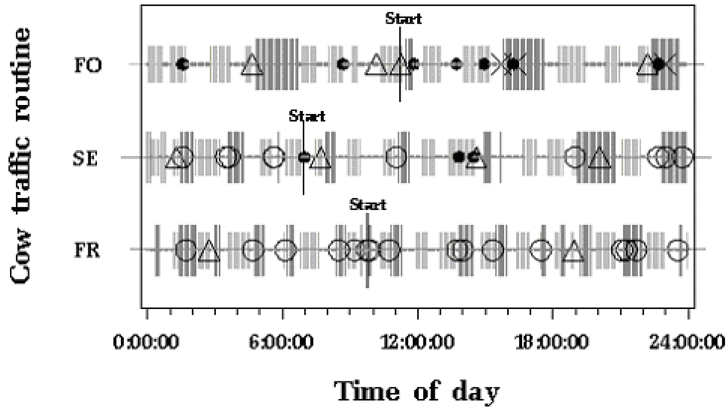


Figure 5a. Temporal pattern of feeding meals (grey areas), rumination (light grey areas), milkings (Δ), passages through the milking unit (×), passages through control gates (○) and redirection in control gates (●) for three 24-hr periods of cow 863 in a forced (FO), selective (SE) and free (FR) traffic routine, respectively. Start= time point when behaviour recording started.

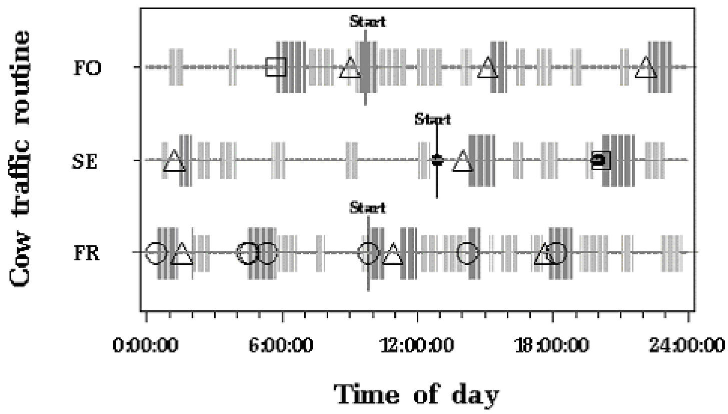


Figure 5b. Temporal pattern of feeding meals (grey areas), rumination (light grey areas), milkings (Δ), passages through the milking unit (×), passages through control gates (○), redirection in control gates (●) and reverse passages through one-way gates (□) for three 24-hr periods of cow 832 in a forced (FO), selective (SE) and free (FR) cow traffic routine, respectively. Start= time point when behaviour recording started.

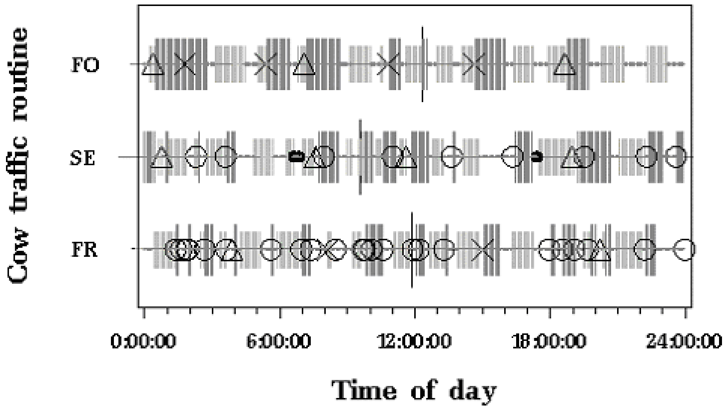


Figure 5c. Temporal pattern of feeding meals (grey areas), rumination (light grey areas), milkings (Δ), passages through the milking unit (×), passages through control gates (○), redirection in control gates (●) and reverse passages through one-way gates (□) for three 24-hr periods of cow 960 in a forced (FO), selective (SE) and free (FR) cow traffic routine, respectively. Start= time point when behaviour recording started.

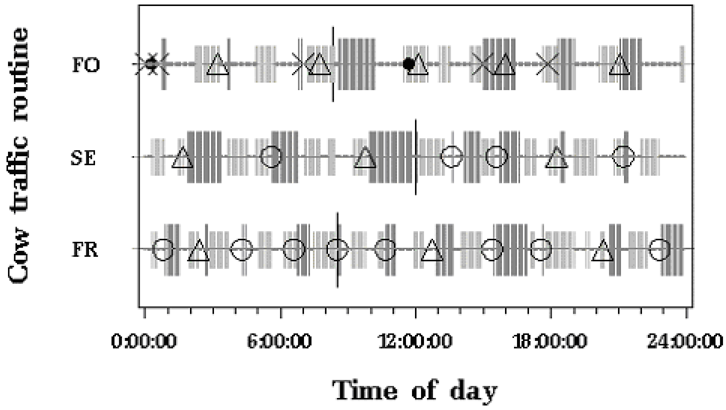


Figure 5d. Temporal pattern of feeding meals (grey areas), rumination (light grey areas), milkings (Δ), passages through the milking unit (×), passages through control gates (○), redirection in control gates (●) and reverse passages through one-way gates (□) for three 24-hr periods of cow 870 in a forced (FO), selective (SE) and free (FR) cow traffic routine, respectively. Start= time point when behaviour recording started.

General discussion

Feeding patterns

Dairy cows, like other species, eat their feed in distinct meals. In the strict sense the total daily feed intake depends on intake per meal and the number of meals obtained per day. In order to analyse feeding patterns, existing models for definitions of a meal was examined. Feeding patterns have been shown to be affected by different management routines, social environment and diets.

Bimodality in biological data

The motivation to feed is the main drive of the cows to visit the feeding area and the MU in the controlled AM system. By examination of the feeding visit intervals to feeding stations, the relation between the feeding patterns of the cows and the cow traffic in AM systems can be revealed. Computerized feeding stations allow for easily obtained data of feeding visit intervals. Examination of such data has shown that visits to feeding stations were clustered in time (Tolkamp *et al.,* 1998; Tolkamp and Kyriazakis, 1999). These clusters can be referred to as meals and with biologically relevant definition of a meal, management effects on short-term feeding patterns can be studied. In paper **I,** the distribution of feeding intervals, after transformation to the natural logarithm, of cows in controlled cow traffic was presented. It showed the typical bimodality that is common in a wide range of biological data of different origin. The reason for this pattern is that feeding is not a continuous process. Instead, animals feed in distinct meals. Many species, ranging from cattle (Metz, 1975) to horses (Mayes and Duncan, 1986) and locusts (Simpson and Ludlow, 1986), exhibit a lack of short intervals between meals, which is the actual cause of the bimodality in the distribution of natural logarithmic feeding visit intervals. The biological explanation to the bimodal shape of inter feeding visit intervals (paper **I**) was explained by the cows preference of ruminating in distinct and long-lasting bouts (paper **IV**).

Meal criteria in studies of meal patterns

A proper definition of a meal is critical for the results of a feeding pattern analysis. In studies of feeding patterns, a meal criterion is usually defined. A meal criterion is the longest interval between two feeding visits not separating two meals. Authors have used definitions of meals that have either been arbitrary or based on the assumption that meals are randomly distributed in time, which has resulted in a wide range of meal criteria having been used for cattle: 10 min (Dado and Allen, 1993); 10 min (Harms *et al.,* 2002); 13 min (Morita *et al.,* 1996); 20 min (Metz, 1975); 60 min (Olofsson*,* 2000). Metz (1975) argued that because of a shortage of intervals of the length 20 to 60 min, the choice of meal criteria within this interval is expected to have a small effect on observed feeding patterns. This was somewhat confirmed in paper **I**, where an average meal criterion ranging from 39.9 min to 52.9 min had marginal effects on feeding patterns. However, in paper **I** a significant difference in average meal criteria was found between cows subjected to different cow traffic routines, suggesting that when estimating management effects on feeding patterns a generalization of meal criteria is not be advisable. The definition of a proper meal criteria is also critical in studies of drinking patterns; Andersson (1984) pointed out that the definition of a drinking meal to a great extent affects the result when describing drinking patterns.

What is common in theories about short-term regulation of feed intake is the concept of satiety (Tolkamp *et al.,* 1998). The concept of satiety predicts that the probability that a cow will initiate a meal is dependent on the time since the last meal. Tolkamp *et al.* (1998) and Tolkamp and Kyriazakis (1999) developed a method for analysing feeding visits that was in accordance with satiety mechanisms. They described the occurrence of meals as the presence of clusters in data of feeding intervals. The intervals within each cluster were assumed to be log-normally distributed, and a mixture of two or three normal distributions was used as a model for the frequency distribution of Natural Logarithm (**LN**)-transformed feeding intervals. In paper **I** we found evidence that feeding intervals occur in two or three populations, depending on the individual cow. When two distributions were included in the model, the intervals were separated into one distribution with short within-meal intervals and another distribution with long between-meal intervals. The meal criterion, i.e. the longest interval between two feeding visits not separating two meals, was then identified as the point where an interval was assigned to both distributions with equal probabilities. When a third distribution was added to the model, the within-meal intervals were further separated into intervals where cows did or did not take a temporary break in feeding to visit the water bowls. In paper **I,** meal criteria were estimated with a narrow confidence interval. Inclusion of a Weibull distribution to describe the inter-meal intervals resulted in a model that predicted that the probability of cows initiating a meal would increase with time since the last feeding occasion, which was similar to observed starting probabilities.

A biologically relevant definition of meal criteria is a prerequisite to evaluate different AM systems with respect to feeding patterns. Defining meal criteria in mixture distribution models will not only yield more reliable results in future studies, but will also allow for direct comparisons of feeding pattern measures between studies. In this respect, different AM-system solutions can better be measured against each other. The observation that starting probabilities increased since the last feeding meal, reveals a mutual relation between the dairy cows' feeding patterns and the efficiency of the cow traffic. Any moves in management that have an effect on the feeding patterns of the cows will also influence the cow traffic.

Meal patterns of dairy cows in AM systems

The introduction of AM systems not only brought on a totally new milking regime, it also involved a new system for feeding the cows. The design of an AM system must allow for a high feed intake and let the cows feed at their desired times. Concerns that controlled cow traffic, and in particular forced cow traffic, might prohibit the cows from performing a natural feeding pattern, which might limit their feed intake and decrease production have been raised in several studies (Ketelaar-deLauwere and Ipema, 2000; Harms *et al.*, 2002; Hopster *et al.,* 2002a b; Luther *et al.*, 2002).

Controlled cow traffic in AM-systems has been shown to decrease the time spent feeding in comparison to loose-housing systems with conventional parlour milking

(Uetake *et al.,* 1997). Hermans *et al.* (2003) reported that a cow traffic system where the cows always had access to the roughage feeding area increased the daily feeding time compared to a system where the roughage was accessible through the milking unit only. Harms *et al.* (2002) observed a lower number of meals and a decreased feed intake when cows were subjected to an increased degree of guiding. Hopster *et al.* (2002 b) suggested that an observed lower milk yield in low ranked cows compared to high ranked cows was explained by the limited access to the feeding area in forced cow traffic situations.

The numbers of meals measured for the selective cow traffic routine in paper **II** (4.9 – 7.2) and for the free (9.0), selective (8.3) and forced (7.0) cow traffic routines in paper **IV** were partly similar to reported studies in literature (Table 2). The study of Ketelaar-deLauwere *et al.* (1998) stands out in measured number of meals in forced cow traffic, which may be an effect of the low number of cows in that study. In paper **II** an increased degree of guiding caused the number of meals to become significantly lower. In addition, the cows prolonged each meal, increased the DMI and the number of feeding visits at each meal. With this change in feeding pattern, the cows managed to keep up the dry matter intake although the number of meals decreased. This is in contrast to Harms *et al.* (2002), where cows had 6.6 meals during forced cow traffic and a negative effect on feed intake was measured. Once again, the meal criterion used in this study was arbitrarily set to 10 min and it is likely that the true number of meals was less than reported. The concern that controlled cow traffic limits the number of meals, the time available for feed intake and thereby the DMI, is based on the assumption that time limits the feed intake of dairy cows. Because feed intake is a function of time spent feeding and feeding rate, this assumption is only true if the cows feed at a maximum feeding rate. Several studies have shown that dairy cows can increase feeding rate as a consequence of social competition (Olofsson*,* 1999; Nielsen*,* 1999). Moderate feeding rates were measured in paper **II** and paper **IV**, suggesting that time was not limiting feed intake in those studies. I conclude that if cows are offered *ad lib.* roughage of good quality (similar to what was fed in the controlled cow traffic study) under normal competitive conditions, controlled cow traffic is not likely to prohibit feed intake if the cows achieve at least 5 meals per day.

The observation that cows learned how to enter the one-way gates in the reverse direction is symptomatic for the social effects that are triggered when the degree of guiding is too high. Such passages only occurred occasionally in the free and the selective cow traffic routines (papers **II** and **IV**) but were common in the forced cow traffic routine. The fact that this behaviour was more common for cows of low social rank suggests that forced cow traffic enhances social effects in the AM system. As far as I know, there are no reports about this phenomenon. This may of course be related to the design of the one-way gates, but can also explain the less than expected differences in voluntary visits to the milking unit between free and controlled cow traffic in some experiments reported in literature. Cows are creatures of convenience, and obviously the challenge of passing through the gates in reverse was more convenient than queuing at the waiting area. In addition, social effects of redirection time (paper **III**) and chewing activities (**IV**) were observed. Ketelaar-deLauwere *et al.* (1996) observed social effects of the timing in the visits to the MU in forced cow traffic. Interestingly, it has also been observed that cows of low social rank in AM systems have lower concentrations of plasma cortisol and higher concentrations of oxytocin than cows of high social rank have. This indicates that cows of low social rank find ways to adapt to the system instead of getting stressed. Low cortisol and high oxytocin concentrations is an indication of antistress (Uvnäs-Moberg *et al.*, 2001).

Table 2. Data from cow traffic studies reported in the literature. Differences in designs and cow traffic routines may have contributed to the variation between studies. Cow traffic routines have either been classified as free (FR), selective (SE) or forced (FO).

Cow traffic routine	No. of cows	Milkings No./cow/d	Total Visits[1] MU No./cow/d	Meals[2] No./cow/d	Reference
FR	30	-	5.4-7.4[3]	9.8-10.8	*Ketelaar-deLauwere et al. (1998)*
FR	57	2.9	3.8	-	*Van'tLand et al. (2000)*[4]
FR	48-50	2.3	2.9	8.9	*Harms et al. (2002)*
FR	46	2.0	2.5	12.0	*Thune et al. (2002)*
FR	58	2.0	2.2	9.0	*(Paper **IV**)*
SE	24	4.0	5.5[3]		*Devir and Maltz (1995)*
SE	61	2.9	3.9	-	*Van'tLand et al. (2000)*[4]
SE	48-50	2.6	3.4	7.4	*Harms et al. (2002)*
SE	50	2.4	4.1	6.5	*Thune et al. (2002)*
SE	60	2.9-3.1	4.7-7.4	-	*Hermans et al. (2003)*[5]
SE	45	2.1-3.3	2.4-3.8	4.9-7.2	*(Paper **II**)*
SE	58	3.5	3.6	8.3	*(Paper **IV**)*
FO	30	-	6.8-7.7[3]	9.0-9.2	*Ketelaar-deLauwere et al. (1998)*
FO	48	2.4	5.4	5.4	*Wendl et al. (2000)*
FO	62	2.7	4.5	-	*Van'tLand et al. (2000)*[4]
FO	48-50	2.6	4.0	6.6	*Harms et al. (2002)*
FO	45	2.6	3.9	3.9	*Thune et al. (2002)*
FO	63	2.5-3.1	3.5-4.4	-	*Hermans et al. (2003)*
FO	58	2.9	5.1	7.0	*(Paper **IV**)*

[1] Milkings and non-milking related visits
[2] Different definitions of a meal may considerably contribute to variation between studies
[3] Visits to a selection unit
[4] A survey on 24 farms in the Netherlands, Denmark and Germany.
[5] The cows had free access to roughage but had to pass the MU to get concentrate.

Dairy cows can adapt their feeding patterns to a high degree of guidance in controlled cow traffic situations without decreasing DMI. Feeding rate reflects the social environment of the cow (Nielsen, 1999), and the social effects on chewing activities measured in paper **IV** represents a normal adaptation to the environment and should not *per se* be considered as a sign on bad cow welfare. But it must be noted that only three cows at the time were subjected to forced cow traffic in the welfare study (paper **IV**), and the degree of social competition would have been higher if forced cow traffic was applied to bigger groups or even the whole herd. Applying forced cow traffic on herd-level is, as has been stated in other studies too, not advisable. Forced cow traffic can be successful in guiding certain individual cows or groups of cows to high milking frequencies. However, because individual cows have different possibilities to adapt to controlled cow traffic (e.g. Figure 5b and 5d) I strongly recommend that all cow traffic routines are applied on an individual cow level.

Milking frequency in management of dairy cows

Expected milk yield increase in AM systems

The introduction of AM systems on commercial farms has aroused much interest among people working with dairy production. Increased milk yield, labour savings, the possibility of production control, improved udder health and better milk quality are expectations of the AM systems. Several physiological mechanisms lie behind increased milk yield when milking more than 2× is applied. There is evidence that an increased removal of a feedback inhibitor causes direct effects on the local control of milk secretion (Hendersson and Peaker, 1984). More long term effects on milk yield are increased activity of key enzymes in the milk synthesis (Wilde *et al.,* 1986) and an increased number of mammary cells, either through cell proliferation or decreased cell involution (Wilde *et al.,* 1986; Hale *et al.,* 2003.

The possibility of milking the cows more than twice a day without additional labour was together with increased flexibility and reduced heavy labour the most important motivation to invest in AM systems among dairy farmers (Hogeveen *et al.,* 2004). Several studies have shown that increasing milking frequency from 2 times daily to 3 times daily at regular milking intervals, results in a milk yield increase of about 10 % (DePeters *et al.*, 1985; Ipema and Benders, 1992). Milking frequency above three times daily milkings has resulted in either a positive (Bar-Peled *et al.*, 1995) or no (Ipema and Benders, 1992) effect on milk yield. Alterations in milking frequency can be used to affect milk production, and could therefore be an important management tool in the AM-system (Devir and Maltz, 1995). Increased milking frequencies can also be useful in management strategies aiming at prolonged lactations (Österman and Bertilsson, 2003). Increased machine on time and the effects on udder health must be considered when evaluating milking management strategies (Ipema and Benders, 1992).

However, recent analyses of data from commercial farms have shown that the high expectations of an increased milk yield with the introduction of milking in AM systems have not been fulfilled. Dutch test-day milk yield data of 150 herds showed that the average milk yield increase was only 2 % after the introduction of AM systems (Wade *et al.,* 2004). Milk yield decreased by 9.8 % on 15 Dutch farms after the installation of AM systems (Poelarends *et al.,* 2004). The lack of a milk yield increase can partly be explained by effects of the transitional period when going from conventional milking to milking in an AM system; Rasmussen *et al.* (2001) observed a slight decrease in yield for a couple of months after the introduction of AM systems on 78 Danish farms. But a year after the introduction, the milk yield had increased by roughly 4 % compared to the yield before the introduction. In a survey of 36 Swedish dairy farms that all had milked their cows in an AM-system for 15 months or longer, there was an average milk yield decrease of 1 % after the introduction of the AM system (Mörck, 2003).

Effects on milk yield in studies under experimental conditions have not been conclusive. Devir and Maltz (1995) did not measure any difference in milk yield for the first 145 d in lactation between cows milked on average 5× compared to 3× in an AM system. However, after the 145 d all cows were milked 2× in a milking parlour, and the cows that had been milked 5× in the first part of the lactation had a more persistent lactation curve. Measured on the whole lactation, the cows milked 5× produced 8.1 % more fat and protein corrected milk. In a study with 66 dairy cows, Svennersten-Sjaunja *et al.* (2000) compared the milk yield in cows milked in a parlour or in an AM system. Cows milked in the AM system had an average milking frequency of 2.4× and yielded 7.0 % more energy corrected milk compared to the parlour milked cows (2× milking).

In line with the result from studies in experimental conditions referred to above, a significant milk yield increase due to a higher milking frequency was observed in the controlled cow traffic study (paper **II**). The amount of concentrate reward dispensed in the MU at every milking was kept low to not confound the effects of a higher milking frequency. I can conclude that if the AM system manages to achieve an average milking frequency difference of one milking per d, it will likely result in an increased milk yield output.

Restricted conclusions can be drawn from on-farm surveys, because they do not take into account the actual milking frequency before and after the introduction of AM systems. In addition, the variation in farms with different conditions is large, which was also noted by Poelarends *et al.* (2004). But the discrepancy in yield responses between experiments and on commercial farms is an indication of problems when implementing the AM systems on commercial farms.

The control of milking frequency in AM systems

The AM system offers the possibility of using milking frequency together with individual concentrates allocation as a control of milk production. This demands a cow traffic system that can control milking frequency according to the management goals of the farmer. Physiological models incorporating information on cow body weight, milk production, milk composition and concentrate intakes can be combined with individual settings of milking frequency and concentrate allocation to manage the cow individually through the course of lactation (Maltz *et al.,* 1992a b; Devir *et al.,* 1997; Maltz, 1997; Maltz *et al.,* 2002). An individual approach to feeding has been shown to increase production efficiency (Maltz *et al.,* 1992 a).

Devir *et al.* (1993) outlined a general description of an AM system consisting of milking units, concentrate stations, control gates, feeding and resting areas. Based on the cows' voluntary visits to the MU and the control gates, the AM system design should be able to maintain an well functioning routine in feeding and milking. A crucial purpose for a successful implementation of an individual approach to management is the AM system capability of guiding cows to preset milking frequency aims. When feed is offered *ad lib.* to dairy cows in free-stall or tied-up systems, multiparous cows typically allocate their DMI to 6.4 to 17.5 meals per day, each lasting for 21.1 to 41.1 min (Vasilatos and Wangsness, 1980; Dado and Allen, 1993; Tolkamp *et al.,* 2002). In theory, if the cow is milked en route to the feeding area, such a frequent meal pattern would result in many opportunities for milking during a day.

The observed milking frequencies in the controlled cow traffic study (paper **II**) were far below what would be possible in theory. In paper **II**, we measured the return time that reflected the cows' preferred inter-meal interval. In the vast majority of observations, the cows returned within the preset time limits of the control gates. The distribution of intervals between successive visits to the control gates is in line with the observations by Devir and Maltz, (1995). They concluded that the very frequent visiting pattern to the gates allows for 5 to 6 milkings per cow and day. Concentrate fed in the milking unit can be used to increase its attraction to the cows. The maximum amount of concentrate that can be fed in the MU is limited by the feeding rate and the time that is available for milking. In the present studies the amount of concentrate was kept at a low level not to confound the effects on milk yield. It can be argued that the 300 grams of concentrate given at every milking in paper **II** was too little for attracting the cows to the milking unit. However, the effect that the amount of concentrate fed in the milking unit has on voluntary visits to the MU is not conclusive. In a survey of 10 Canadian farms, the amounts of concentrate fed in the milking unit at every milking varied between 1.5 to 4.5 kg, but the average number of voluntary visits was about 2 with a small variation between farms (Roodenburg and Wheeler, 2002). In another experiment, there was no difference in voluntary visits to the milking unit when cows were offered 1.2 kg of concentrate at every milking compared to when they were offered 1.7 kg (Halachmi, 2004). In contrast to these two studies, in one European region out of three surveyed, Van't Land *et al.* (2000) found a positive relation between the amount of concentrate fed in the milking units on farms and number of voluntary visits.

Redirection time is a measure of the cow's motivation to feed, be milked and her possibility to advance in the queue in front of the milking unit (paper **III**). Average redirection time was of a considerable length and showed a wide individual variation (paper **II** and **III**). To successfully guide cows towards target milking frequencies, two prerequisites must be fulfilled; 1) the cows must frequently show up in the control gates; 2) the time from a redirection in the gates until showing up for milking must be short. Based on the results mentioned above, I can conclude that prerequisite number one was fulfilled by the studied system, but not prerequisite number two. For a full implementation of an individual approach to management, efforts have to be made to reduce redirection time.

An individual approach to cow traffic

Albright (1987) stated that cows are “creatures of habit”, which has been shown in several studies. Ketelaar-DeLauwere *et al.* (1998) noticed individual differences in how cows used the selection unit in an AM system, and Hopster and Blokhuis (1994) found that cows responded to a social stressor in a way that was characteristic for the individual animal. Hopster *et al.* (1998) studied the side preference of cows in a two-sided milking parlour and found that side preference was stable over a long period of time. Further, Shrader (2002) found that spontaneous behaviour, such as length of lying time and overall activity, was consistent over time for individual cows. DeVries *et al.* (2003) observed a high within cow repeatability of measures related to feeding patterns.

In the controlled cow traffic study, most of the random variation of model parameters was observed to be variation between individual cows, and only a small part was variation within individual cows (paper **I**). The cows had a wide variation in individual average return time (paper **II**), in individual redirection time (paper **II** and **III**) and in individual milking interval (**III**). There also seemed to be an individual difference in how cows responded to a redirection in control gates (paper **III**). Because of the observed individual variation in return time in the controlled cow traffic study, it is concluded that time settings on group level in control gates have no fair biological basis (paper **II**). A selective cow traffic routine can be equal to forced cow traffic for individual cows that have long return times and, as a result, consistently are redirected in the CG. It can be concluded that the outcome of a cow traffic routine on group level is, because of the individual variation, highly unpredictable. Care should be taken when interpreting the distributions of return time for the ($G_{4\text{-}8}$) cows (Figure 4). A return time was only measured when the cows registered in the CG (Figure 2), and if cows learned the time settings in the gates and deliberately avoided registering in them at times they knew they would be redirected, the true proportion of long return times might be greater than what is shown in figure 4 and in paper **II**. The temporal patterns in activities of the cows confirm that the response to a cow traffic system is highly individual (Figure 5).

Stress responses in dairy cows subjected to controlled cow traffic

Common strategic goals in the AM herds are maximum production, labour savings, maximal economic output or any combination of these. However, the welfare of the dairy cow must not be neglected in the strategic planning.

Based on observed individual visiting patterns to milking units (Prescott *et al.,* 1998) and the view that cows are “creatures of habit” (Albright, 1987), it has become a consensus of opinion that the cow’s freedom to choose her own activities is in agreement with improved animal welfare. This is in favour of holding cows in automatic milking systems, because in these systems cows can feed and visit the milking unit of their own accord. When the degree of controlled cow traffic is increased by the introduction of control gates, the free choice of the cow is limited. This inflicts restrictions in the cow’s possibility to act in synchronisation with other herd mates, which may be a cause of frustration (Hurnik, 1992; Winter and Hillerton, 1995). Because dairy cows usually prefer to perform their activities in synchrony, cows of low social rank were obliged to visit the feeding areas at less popular times (Ketelaar-deLauwere *et al.,* 1996), suggesting a higher degree of frustration for these cows. However, it can be questioned if these changes in behaviour should be considered as an innocuous adaptation to the system or as an abuse of cow welfare.

Cortisol measurements

In paper **IV** it was hypothesised that the actual redirection in a control gate may be frustrating, both from being excluded from the feeding area and from the act of waiting in front of the milking unit. Hopster *et al.* (2002a) compared behavioural and physiological stress responses of cows milked in an AM system with forced cow traffic or in a conventional milking parlour. They concluded that no indications of stress in either of the two milking systems were found. However, they measured a tendency towards higher plasma cortisol concentrations a few minutes after milking for cows milked in the AM system compared to the conventional system. There is a time lag from the first exposure to a stressor until the release of cortisol from the adrenal cortex, indicating that the cows encountered a negative experience during the time before milking (presumably in the waiting area). An alternative explanation for the increased plasma cortisol would be that milking induced a release of cortisol (Gorewit *et al.,* 1992).

Fraser and Broom (1990) stated that any situation that results in some individual trying to feed but being excluded from the food source is a bad one. In paper **IV** we tested the hypothesis that the redirection in control gates and the act of waiting were stressful to the dairy cows. Because no manual observations were performed in that study, waiting time was extracted from the AM database. It was expected that cows aversive to the waiting area would have longer waiting times and have a higher adrenocortical activation. In contrast to this, it was found that the waiting time was negatively related to cortisol concentrations in milk. The cause could not fully be explained, but it is likely that when the cows for some reason have an elevated adrenal activation, they are prone to advance fast in the queue in front of the MU. Hopster *et al.* (2002 b) did not find any correlation between queuing time and baseline levels of plasma adrenaline and plasma cortisol for primiparous cows. They concluded that gaining access to the MU by primiparous cows did not trigger a physiological stress response. In paper **III,** cows that had redirection times longer than 60 minutes spent more time in the cubicles, but also had more transitions between the different parts of the barn. This indicates that the cows were not at ease after being redirected in the gates.

Cows of high social rank had significantly higher milk cortisol concentrations than cows of low social rank had. This is in line with Olofsson and Svennersten-Sjaunja (2004), who observed lower cortisol concentrations and higher oxytoxin concentrations in the plasma of socially low-ranked cows than in that of socially high-ranked cows, which further indicates that cows of low social rank accepted their situation.

Verkek *et al.* (1998), showed that cortisol in milk was a sensitive measure of plasma cortisol and suggested that milk cortisol may be a good indicator of exposure to stress when milk samples are obtained during or shortly after a period of elevated plasma cortisol concentrations. Fox *et al.* (1981) concluded that elevations in plasma cortisol that occur early in the between-milking period may not be identified as an elevated milk cortisol concentration in the subsequent milking, but that chronic elevations of plasma cortisol from exposure to stress probably would be so identified. Peak values of cortisol in milk were reached 30 min after exposure to stress (Termeulen *et al.,* 1981). Measurement of milk cortisol concentrations can be expected to reflect the experience a short time before milking. The decision to measure cortisol concentrations in milk rather than in plasma (paper **IV)** was therefore well motivated.

In paper **IV** it was found that milk cortisol concentrations were higher during the selective cow traffic routine compared to the forced and free cow traffic routines. The difference was rather low and within the range of basal levels of milk cortisol that has been reported by others. However, it is possible that the cows lost some of the ability to predict the decision of the gates in the selective cow traffic routine, and therefore responded more strongly to redirections. The ability to predict and control stressful stimuli has been shown to be very important in psychological stress (Friend, 1991). Neuffer *et al.* (2004) found no differences in milk cortisol concentrations between cows milked in a different AM systems or in a conventional parlour. Lexer *et al.* (2004) found no significant effects on chronic stress in dairy cows milked either in a conventional parlour or in an AM-system when measuring the concentration of glucocorticoid metabolites in faeces, which was also found by Möller and Alm (2004).

It was shown that with less intensive stressors, the glucocorticoid response decreased upon repeated exposure in rats (Natelson *et al.,* 1988). Gwasdauskas *et al.* (1980) observed that the response of the adrenal cortex to repeated activation with exogenous ACTH decreased. Farm animals that have been accustomed to a stressor respond with less stress than animals that have not been accustomed (Grandin, 1997). Chronic exposure to stress caused habituation in the HPA-axis in cattle (Munksgaard and Simonsen, 1996; Munksgaard *et al.,* 1999). We recognize that due to the possibility of adaptation, a normal cortisol level does not exclude that the cows experienced stress, but the presence of increased cortisol levels is a strong indication for it.

Rumination –a behaviour related to antistress?

Oxytocin has shown to have effects on behaviour. Treatment with exogenous oxytocin enhanced positive social interaction, maternal behaviour and sexual behaviour (Uvnäs-Moberg *et al.,* 2001). In breast-feeding women the level of oxytocin has been shown to be related to the degree of calmness (Nissen *et al.,* 1998). There are oxytocin neurons terminating into the hypothalamic-pituitary portal system. By this pathway, oxytocin may have effects on the release of adrenocorticotrophic hormone and as a result also generate effects on cortisol release. Treatment with oxytocin has been shown to induce an anti-stress like pattern. This seems to be related to an increased expression of α_2-adrenoreceptors, which, when activated, inhibit the sympathetic nervous system and enhance the parasympathetic activation (Uvnäs-Moberg *et al.*, 2001). Johansson *et al.* (1999) observed a positive relation between oxytocin levels and the amount of time that dairy cows lay down while ruminating. Andersson *et al.* (1958) discussed the possibility that teat stimulation at milking activated brain centres that were both related to oxytocin release and the motivation to ruminate. Herskin *et al.* (2004) observed that cows exposed to a stressful situation had a decreased rumination time. In paper **IV** we hypothesised that controlled cow traffic would induce stress in dairy cows, and that this might be reflected in a reduced rumination time; but there were no overall significant effects on feeding or rumination patterns, despite the fact that we chose to compare two extreme cow traffic solutions (free vs. forced cow traffic).

Neither cortisol concentrations in milk or rumination time were affected by the increased degree of guiding in the AM system. The concern regarding reduced welfare in dairy cows housed in AM systems has not gained support in the results reported in this thesis. I conclude that there is no evidence that dairy cows suffer from severe stress when subjected to controlled cow traffic routines in AM systems.

Implications

Since the first AM system was installed on a commercial farm in the Netherlands 1992, several system layouts have been presented in order to improve the cow traffic. In the studies presented in this thesis, control gates and an open waiting area have proved to be able to control the production on herd level without restricting feed intake and without imposing stress on the dairy cows. However, because of individual differences in feeding patterns and long redirection times, the full potential of the cow traffic system is far from being used. With no further improvements in the decision-making of the cow traffic system, existing milking frequency strategies for control of milk production cannot be implemented.

Improved decision-making in controlled cow traffic with an open waiting area

So far, the general discussion has focused on controlled cow traffic with an open waiting area, and pointed to the effects on dry matter intake, milk production and the stress response. Further, I have shown the relation between individual feeding patterns and the success of the applied cow traffic routines. I also came to the conclusion that based on the wide range of individual responses to the controlled cow traffic routines, time settings on group level have no fair biological basis. It was also stressed that the cow's voluntary feeding pattern allows for frequent visits to the control gates and thereby offers many opportunities to milk her. However, because of long redirection times, the control gates failed to guide cows to frequent milking. In the following passages, I would like to discuss further elaborations of the controlled cow traffic system with an open waiting area. The discussion is mainly focused on improvements of the decision making process of the control gates, and to a smaller degree the system design. However, the barn layout has been shown to affect the functionality of the AM system significantly (Halachmi *et al.,* 2000). The elaboration of the AM system is based on the points that I have brought up in the discussion so far, and the suggestions I give here have not yet been evaluated in practice.

An improved decision making for the control gates should aim at allowing cows to feed in accordance with their voluntary meal patterns, directing cows to milking in order to reach the strategic goals that the farmer has set up for each individual cow, preventing the build up of a queue at the waiting area and thereby decreasing redirection time. Such decision making must be able to incorporate on-line information such as: 1) individual meal patterns and expected return times, 2) expected redirection times of individual cows, 3) identification of the cows in the waiting area. In commercial AM systems without any feeding registration, the exit gates from the feeding areas need to be equipped with antennas for time and cow identification (Figure 6). This would enable the recording of individual feeding patterns, which could form the basis of the control gate decisions. Allowing one non-milking related meal between every milking guarantees a high visiting frequency to the control gates. In an individual-oriented approach to controlling cow traffic, the feeding pattern determines the highest possible milking frequency, i.e. we have to accept that some cows with long return times cannot reach very high milking frequencies. It can be expected that the variation in milking intervals within cows is lowered when individual decision making is applied.

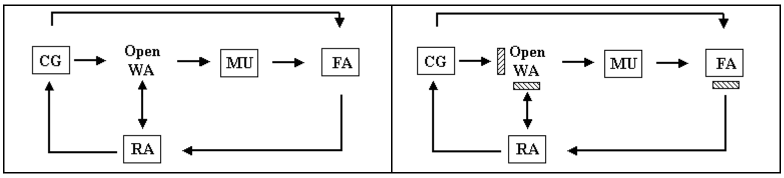


Figure 6. A simplified layout of the cow traffic in the present studies (left) and an elaborated version of the system (right) equipped with antennas for cow identification (striped boxes). Abbreviations: CG=control gates, FA=feeding area, MU=milking unit, RA=resting area, WA=waiting area.

If antennas for cow identification are positioned at the passages to and from the waiting area, information on queue length and the number of cows that are waiting could be useful (Figure 6). In the study reported in paper **III**, cows seemed to respond individually to redirections in the gates. With information on queue length, time since last feeding and milking and individual response patterns, the expected redirection time could be estimated. If a cow registers in the gates at a time when the waiting area is very busy, e.g. shortly after a system cleaning, and she is expected to get a long redirection time, it may be a better idea to let her pass through the gates although she is ready for milking.

In order to reduce the redirection time, queue length must be shortened. This can possibly be done by introducing a set of rules for prioritisation in the milking order. If a cow that is close to her strategic goal registers in the control gates, the system can decide to let her pass the gates and prioritise cows that are already in the waiting area and that have a higher divergence in actual and target milking. The system could be set to prioritise cows in early lactation in order to not jeopardize the cell proliferation and the carry-over effect of milking that has an effect on the production over the whole lactation (Bar-Peled *et al.,* 1995). Further, cows with high somatic cell counts and subclinical mastitis could be given priority over other cows. The diurnal visiting pattern could also be useful information. For example, some cows may consistently register in the gates or in the milking unit at times when the system is not usually busy. In case such a cow is not too far from getting milking permission, it might be a good idea to milk her in order to save some system capacity.

The available milkings in an AM system should be used in the most optimal way. The above suggestions for improved decision-making must be evaluated in computer simulations and under real experimental conditions. Because of the existing relation between milking interval, milk flow rate, handling time during milking and milk output (Koning and Ouweltjes, 2000), effects on milking capacity should be considered in such simulations.

Some AM systems presented in the literature have closed waiting areas (e.g. Hermans et al., 2003). The idea behind this design is that cows are caught by the system when registered in the control gates, and thereby prevented from returning to the resting area before they are milked. It can be expected that this design decreases the variation in milking interval. However, unless the decision-making process is enhanced, the problem with long redirection times remains unsolved and these systems will not likely generate improvements in the cow traffic. In addition, the closed waiting area offers no chance for low ranked cows to leave the area when it is crowded, which decrease their possibility to control their situation. This might lead to stress in low ranked cows.

Practical implications of these studies

Control gates and an open waiting area offer the possibility of controlling cow traffic and thereby affecting the milk production, which gives controlled cow traffic a potential as a management tool. The concern that cows do not have the possibility of *ad lib.* feed intake when the number of meals is restricted by controlling cow traffic could not be confirmed. The cows on average obtained 5 meals during the high degree of guiding (paper **II**), and provoking fewer meals than that is not recommended. Here it must be stressed that a system that counts the number of meals only reflects the feeding patterns if the cows have the possibility to feed during a meal, i.e. feed must be delivered in such amounts that troughs never are empty.

Controlled cow traffic did not provoke an increased adrenocortical stimulation but the fact that cows learned to pass the selection gates in the opposite direction to during the forced cow traffic indicated that they had difficulties in adapting their feeding pattern to the cow traffic routine. In addition to this, the forced cow traffic routine provoked social effects on behaviour, which calls for the appliance of selective or free cow traffic on herd level. Because of the individual differences in return time and the fact that several cows stopped trying to pass the control gates (paper **II**), it is not recommended to set the time limits lower than 4 hrs in the control gates. In the controlled cow traffic study, one cow with a high average return time never started to use the control gates regularly during the high degree of guiding (MF_4). But when the cow traffic routine was changed to the lower degree of guiding (MF_8) she started to visit the gates frequently. Again, this is an observation that calls for an individual approach to cow traffic.

To give farmers advice on manually adjusting control gate settings to individual cows might be fruitful for the very interested and ambitious farmer. However, manual examination of the available system data is time consuming and if misinterpreted there is an overhanging risk of making wrong management decisions. Hence, individual decision-making must be conducted automatically and be able to incorporate available on-line information.

Comments on practical implications

The practical implications discussed above are based on the fact that cows have an active feeding pattern, i.e. the return time is low and the visiting frequency to control gates is high. It is only during these conditions that control gates offer the possibility of controlling the cow traffic. Lazy feeding patterns have been observed when cows are offered total mixed diets with high proportions of grains (Rodenburg and Wheeler, 2002). This is detrimental to the cow traffic, but it is a problem different from the problem with long redirection times that was observed in the present studies (papers **II** and **III**).

Conclusions

1. Modelling feeding visit intervals in mixtures of Gaussian and Weibull distributions gave estimated biologically relevant meal criteria.

2. Cow traffic systems with control gates and an open waiting area offer the potential to control average milking frequency in the herd and thereby increase the milk production.

3. Cow traffic systems with control gates and an open waiting area do not restrict the dry matter intake of the cows, at least as long as the number of obtained daily meals is equal to or more than five.

4. When the time limits in the control gates were too short, the possibility of making a non-milking related meal decreased, resulting in some cows giving up trying to pass them.

5. Forced cow traffic made it difficult for some cows to adapt their feeding pattern to the system, and forced cow traffic triggered social effects at the waiting area and in the feeding area. A high degree of guiding should therefore only be applied on an individual cow level.

6. Cows showed no evidence of being severely stressed when redirected in control gates placed at the entrances to the feeding areas.

7. The cows had a frequent meal pattern, which offered many possibilities to milk them. Because of long redirection times, the cow traffic system failed in directing cows to the MU at short notice.

8. Because of a wide individual range in return times, time settings on a group level have no biological relevance.

9. Dairy cows show individual response patterns to cow traffic routines.

10. To fully make use of the potential to control cows towards target milking frequencies, an improved decision-making needs to be developed. It should incorporate on-line information about individual feeding patterns, predicted redirection time, and the queue situation in the waiting area.

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Populärvetenskaplig sammanfattning

Denna avhandling baseras på tre olika studier genomförda i det automatiska mjölkningssystemet på Kungsängens forskningscentrum, Sveriges Lantbruksuniversitet i Uppsala. Resultaten från studierna är rapporterade i fyra olika vetenskapliga artiklar som presenteras i slutet av denna avhandling. I studierna har jag studerat hur kornas mjölkproduktion, foderintag, ätbeteende och stressnivå påverkas när olika kotrafik tillämpas i automatiska mjölkningssystem.

Sedan det första automatiska mjölkningssystemet installerades på en svensk gård 1997, har antalet system i Sverige ökat till cirka 400 installerade på 250 olika gårdar runt om i landet. Det betyder att i storleksordningen 20,000 svenska kor mjölkas i automatiska mjölkningssystem idag. Den ursprungliga orsaken till att automatiska mjölkningssystem utvecklades var ökade kostnader för foder och arbete samt minskande mjölkpriser. Det finns höga förväntningar på att automatiska mjölkningssystem skall leda till minskad arbetstid, mer flexibla arbetstider för lantbrukaren, förbättrad djurvälfärd och ökad mjölkavkastning.

I experimentstudier uppfylls ofta förväntan på en ökad avkastning till skillnad från studier på gårdsnivå där en utebliven avkastningsökning ofta observeras. Detta beror delvis på svårigheterna att göra rättvisande gårdsstudier, men visar också på problem relaterade till en ej fungerande kotrafik. I denna studie ökade mjölkavkastningen 10 % när antalet mjölkningar ökade från två till tre gånger per dag. Flera mjölkningar påverkar nämligen juvercellerna dels till att bli fler i antal och dels till att mer effektivt syntetisera mjölkens olika komponenter. Detta kan utnyttjas i nya skötselsystem för mjölkkor. Till exempel, en ökad mjölkningsfrekvens de första veckorna efter kalvning har visat sig påverka hela laktationens avkastning positivt, även efter det att mjölkningsfrekvensen har återgått till 2 gånger per dag. Det kan vara till nytta för lantbrukare som vill förlänga laktationen på sina kor. Idag mjölkas ofta alla kor lika många gånger om dagen oavsett deras avkastning. Högavkastande kor kan man behöva mjölka fler gånger för att de inte skall få alltför spända juver. Dessutom är en hög mjölkningsfrekvens bra för juverhälsan eftersom mikroorganismer som orsakar juverinflammation effektivt tas bort från spenkanalen vid varje mjölkning. Med ett automatiskt mjölkningssystem finns möjligheten att med en oförändrad arbetsinsats variera antalet mjölkningar för att passa lantbrukarens skötselstrategi och kornas behov.

I det automatiska mjölkningssystemet får korna efter egen vilja gå till foderavdelningen för att äta och själv bestämma när hon skall besöka mjölkningsroboten för att mjölkas. Att kon på detta sett får råda över sin vardag anses vara lugnande eftersom hon har större kontroll på sin vardag. Att mjölkas är i sig inte tillräckligt lockande för att kon skall besöka mjölkningsroboten tillräckligt ofta, och för att öka mjölkningsfrekvensen hos korna är många automatiska mjölkningssystem utrustade med kontrollgrindar som ställs mellan liggavdelningen och foderavdelningen. Med dessa grindar tvingar man kor som inte mjölkas tillräckligt ofta att gå vägen via mjölkningsroboten och bli mjölkade när de skall äta i foderavdelningen. När kon måste stå och vänta i kön framför mjölkningsroboten för att få äta resulterar det i att hon får färre måltider per dag. Många har trott att detta hindrar kon från att äta så mycket foder hon vill, vilket inte skulle vara bra för hennes näringsstatus. I denna studie mätte vi foderintaget för korna när de var olika hårt styrda, d.v.s. när korna hade tillåtelse att passera grindarna olika lång tid efter mjölkning. Detta hade ingen effekt på deras foderintag, och därför kan påståenden om att styrning av kotrafiken skulle hindra korna från att äta avfärdas. Ett varningens finger är dock på sin plats! En alltför hårt styrd kotrafik fick en del kor att ge upp att besöka grindarna och fick därför väldigt få måltider. Det visade sig också att när grindarna var helt stängda (helt styrd kortafik), hade korna svårt att anpassa sitt naturliga måltidsmönster till kotrafiken. Dessutom provocerades sociala effekter i besättningen fram, d.v.s. att kor med en låg social rang fick svårare att hävda sig på väntytan framför mjölkningsroboten samt i foderavdelningen. Därför rekommenderas att alltid låta kor ha möjlighet att passera genom grindarna upp till fyra timmar efter senaste mjölkning.

Blir korna stressade av att inte få gå igenom grindarna för att äta? Detta var en annan av frågorna jag ställde mig i studien. Bland sociala djur råder principen att ”djur beter sig som andra djur”, d.v.s. de äter när de andra i flocken äter och vilar när de andra djuren gör det. Detta kallas inom husdjursvetenskapen för social facilitering. Man kan tänka sig att en ko som nekas att passera en grind in till foderavdelningen när hon är hungrig och dessutom ser sina flockmedlemmar stå och äta skulle bli frustrerad och stressad. För att testa om detta var sant eller ej, mättes koncentrationen av kortisol i kornas mjölk, vilket är ett hormon som frisätts när kor blir stressade. Tiden som kor idisslade under en dag mättes också eftersom idissling är ett beteende som kon utför när hon är lugn. Tiden som kor idisslade samt koncentrationen av kortisol var på samma nivå för kor som ständigt blev nekade i grindarna som för de som aldrig blev nekade i grindarna. Slutsatsen blir därför att kor inte blir stressade av att bli styrda med grindar i automatiska mjölkningssystem.

När en ko blivit nekad att passera en kontrollgrind kunde det ibland ta väldigt lång tid tills hon kom in i mjölkningsenheten. Denna tid kallas för styrningsstid och speglar kornas möjlighet och motivation att ta sig förbi kön framför mjölkningsenheten. Anledningen till långa styrningstider var framförallt att korna undvek att ställa sig i kö på väntytan framför mjölkningsenheten. I denna studie visade det sig att socialt lågrankade kor höll sig nära mjölkningsenheten för att kunna ”smita in” när möjligheter gavs. På så sätt lyckades de korta sin styrningstid. Långa styrningstider minskar möjligheten att styra kor mot en viss mjölkningsfrekvens. Beslutsystem som gör prioriteringar i ordningen som kor skall mjölkas samt tar hänsyn till individuella kors ätmönster bör kunna minska köerna framför mjölkningsenheten, och därmed korta kornas styrningstid.

Kor är mycket mer individer än vad man kan tro. I denna studie visade det sig att kornas foderbeteende var högst varierande mellan individuella kor. Exempelvis föredrog kor att ha olika lång tid mellan sina måltider. Dessutom visade korna olika intresse av att besöka mjölkningsenheten efter att de blivit nekade att passera genom en kontrollgrind. Denna individuella skillnad är viktigt att ta till sig i utvecklingen av nya skötselsystem för mjölkkor. Idag betraktas alla kor likadana och våra sköteselsystem är anpassade efter detta. Om man genomför en skötselrutin på gruppnivå kommer därför endast ett fåtal av korna att svara så som man hade förväntat, vilket leder till en ineffektiv skötsel. Vi försökte exempelvis i denna studie styra grupper av kor mot olika mål-frekvenser i antal mjölkningar. Resultatet blev en vid variation i det antal mjölkningar som olika individer uppnådde, bara ett fåtal kor träffade målet. Med styrning av kor på gruppnivå blir det alltså en omöjlighet att applicera de olika mjölkningsstrategier som nämndes i början av detta kapitel. En slutsats av denna studie är att styrning av kotrafik måste ske på individnivå för att möjligheterna med att använda automatiska mjölkningssystem som ett skötselverktyg fullt ut skall förverkligas.

Några slutsatser från studien:

- Kors foderintag är inte en slumpmässig process, de äter i klart avgränsade måltider. En biologiskt relevant definition av en måltid behövs för att kunna studera kors ätbeteende.
- Styrningstid (tid mellan styrning i en grind till att kon mjölkas) speglar kornas motivation att äta och mjölkas samt hennes möjlighet att passera kön framför mjölkningsenheten.
- Kons huvudsakliga motivation för att besöka mjölkningsenheten är viljan att äta, men även mjölkning i sig verkar ge en viss belöning.
- En ökning av antalet mjölkningar från två till tre gånger per dag resulterade i en avkastningsökning på cirka 10 %.
- Styrning av kotrafiken resulterar inte i ett minskat foderintag om korna har möjlighet att passera grindarna till foderavdelningen upp till fyra timmar efter mjölkning.
- Det är kornas individuella måltidsintervall som avgör hur många mjölkningar som kan uppnås för varje ko. Majoriteten av korna hade korta intervall mellan måltider vilket tillåter en hög mjölkningsfrekvens.
- Många kor undvek att ställa sig i kö framför mjölkningsenheten efter att de blivit nekade att passera kontrollgrindarna, vilket nedsätter grindarnas möjlighet att styra korna till individuella målfrekvenser.
- Kor visar inga tecken på att bli stressade när de styrs med kontrollgrindar.
- Kor uppvisar en stor variation i sitt beteende när de utsätts för olika sorters kotrafik.
- Ett beslutssystem till kontrollgrindarna som tar hänsyn till individuella kors ätmönster och möjlighet att ta sig förbi kön på väntytan behöver utvecklas.

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