Technical and Management Tools in Dairy Production

Improvements in Automatic Milking Systems and Detection of Cows with Deviating Behaviour

H.H. Oostra
Faculty of Landscape Planning, Horticulture and Agricultural Science
Department of Agricultural Biosystems and Technology
Alnarp

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Abstract

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The introduction of Automatic Milking Systems (AMS) has created new aspects both in the planning of dairy cowsheds due to the necessity of directing cow traffic, and in general cow management.. The aims of this thesis was to study some of these aspects, such as, the effect of feeding frequency on Waiting Time at the AMS, cowshed facility utilization, and the effects of light Conditioned Reinforcement on the time needed for cows to leave the Automatic Milking Unit (AMU) after a successful milking. In addition, a method to trace cows in a loose housing system and a method to detect cows with deviating locomotion were evaluated. The results of these studies are given in five different papers.

In the first experiment it is shown that increasing the forage feeding frequency can substantially reduce the cow waiting time before an AMU. The average waiting time at the AMU when feeding twice per day (08:00 and 16:00 hrs) was 755 sec. When the feeding frequency was increased to six times per day (00:00; 04:00; 08:00; 12:00; 16:00 and 20:00 h, respectively), the waiting time decreased to 351 sec. The Feeding Activity Factor (the factor describing the number of times a cow was observed at the feeding fence 10 min after a forage supply) was also higher and the cowshed facilities in the waiting area (floor and cubicles) were more evenly used . No significant differences were found when comparing the utilization of the facilities in the cowshed, although the feeding fence tended to be more evenly used when 6 feedings per day were given, in comparison to feeding twice daily.

To maximise the number of milkings per day per milking stall, the use of the AMU should be as effective as possible, with the time necessary for the cow to enter and leave the AMU as short as possible. In the second study, the effect of a light Conditioned Reinforcement in the form of an acoustic signal followed by either a moving tube rubbing the sides of the cow or a flashing light, was studied on the time needed for cows to leave the unit. It was found that the exit time for primiparous cows decreased by 93-97 sec. For multiparous cows the exit time decreased by 112-168 sec. No negative effect could be found on the time needed for the cows to enter the AMU or on the milking stall visiting pattern. In practise, this meant that 100 and 150 min daily would be available for additional milkings per AMU.

In loose housing herds, the tracking of individual cows can provide answers to questions regarding the effect of cowshed layout and managerial practises on behaviour and on health and oestrus status of the animals. In the thesis, a method is described that can automatically track and identify individual cows in a loose house system by optical means. In addition, a method was developed to detect cows with locomotion problems using body weight distribution. While the results were promising for both methods, more studies must be performed before they reach a satisfying level of acceptance.

Keywords: Automatic Milking System, Automatic Milking Unit, Behaviour, Feeding Frequency, Waiting Time, Conditioned Reinforcement, Optical Real Time Location System, Body Weight, Cow Locomotion, Symmetry Factor.

Author's address: Huibert Oostra, Department of Agricultural Biosystems and Technology (JBT), Swedish University of Agricultural Sciences (SLU), P.O. Box 59, SE-230 53 Alnarp. Sweden. E-mail: huibert.oostra@jbt.slu.se

Elk nadeel heb z'n voordeel
Johan Cruijff

Contents

Abbreviations

AMS	Automatic Milking System
AMU	Automatic Milking Unit
AGRF	Average Ground Reaction Force
CR	Conditioned Reinforcement
FAF	Feeding Activity Factor
GRF	Ground Reaction Force
LED	Light Emitting Diode
LS	Locomotion Score
NS	Neutral Stimuli
NTT	New Technology Test
ORTLS	Optical Real Time Location System
RFSU	Radio Frequency Synchronisation Unit
RFSRU	Radio Frequency Synchronisation Receiving Unit
SF	Symmetry Factor
SJV	Swedish Board of Agriculture
WA	Waiting Area (in front of an AMU)

Appendix

Papers I-V

This thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Oostra, H. H., Stefanowska, J. and Sällvik, K.
The effects of feeding frequency on waiting time, milking frequency, cubicle and feeding fence utilization for cows in an automatic milking system. *In prep.*

Oostra planned the experiment and was responsible for collecting and analysing the data concerning cowshed utilization and for writing the paper.

II. Oostra, H. H., Forkman, B., Sällvik, K., Herlin, A. and Englund, J-E.
Using conditioned reinforcement as a way to make dairy cows to leave an automatic milking unit. *Submitted to an international peer reviewed journal.*

Oostra was responsible for collecting and analysing the data and for writing the paper.

III. Oostra, H. H., Sällvik, K., Braiman, M., Patt, B., Bank, L. and Halachmi, I.
Automatic identification and determination of the location of dairy cows using an Optical Real Time Location System; Part 1. System description. *Submitted to an international peer reviewed journal*

Oostra was responsible for writing the paper.

IV. Oostra, H. H., Sällvik, K., Braiman, M., Patt, B., Bank, L. and Halachmi, I.
Automatic identification and determination of the location of dairy cows using an Optical Real Time Location System; Part 2. System application and evaluation *Submitted to an international peer reviewed journal*

Oostra was responsible for collecting and analysing the data and for writing the paper.

V. Oostra, H. H.
An automated method to detect locomotion disabilities in cows (Manuscript).

Oostra was responsible for collecting and analysing the data and for writing the paper.

General introduction

The degree of freedom for a dairy cow is limited, although it varies with the cow housing system. In Sweden, tie-stall housing systems are still the most common method of keeping dairy cows. Although there is no legislation that states that dairy cows should be kept in loose house systems, it is officially recommended to do so (Swedish Board of Agriculture, 1994). The number of cows kept in loose housing systems is still very low in Sweden. In 2004, only 27% of the cows were kept in these systems (Swedish Dairy Association, 2004). However, the proportion of cows in loose housing will increase at the same time as the average herd size also increases. At present, the average herd size in Sweden is 41 dairy cows per herd (Swedish Board of Acriculture, 2004). The National Board of Agriculture in Sweden has stated (according to the Animal Welfare Ordinance "Regulations and General Recommendations concerning Animal Management in Agriculture") that in cowsheds with cubicles, one cubicle should be available for every single cow, permitting all cows to lie down simultaneously. It is required to have one feeding place per cow if restricted feeding is applied. The width of the feeding place depends on animal weight, 0.6 m for cows less than 500 kg, 0.7 m for cows under 650 kg and 0.75 m for cows with a weight exceeding 650 kg. A maximum of three cows per feeding place is allowed when unrestricted (ad libitum) feeding is used (Swedish Board of Agriculture, 2003).

These regulations aim to guarantee a right to feed and rest for each cow in the herd, and hence to make the situation for the cows as comfortable as possible. The regulations may be adjusted if new technologies are developed and introduced, or if novel management procedures are applied. The latest major introduction of new technology in dairy production has been the Automatic Milking System (AMS), or milking robot, as more popularly termed[1]. This system may become the second largest technical breakthrough in dairy production since the introduction of the double chambered teat cup at the beginning of the twentieth century (British Patent, 1902, cited in Hall, 1979). New technologies are not always directly accepted by farmers. Fifty years after the patent had been filed, only 40% of the farmers in the United Kingdom had switched to machine milking. It required another 25 years before more than 95% used a milking machine (Hall, 1979). How fast automatic milking generally will be accepted remains to be seen. In Sweden, the first AMS was installed in 1998, and 6 years later 274 farmers had invested in an AMS out of 9,700 dairy farms.

What were the incentives for the development of the AMS?

The primary incentives for the development of automatic milking by a robot was an awareness of the great market potential (Parsons, 1988), coupled with a vision of providing the dairy farmer with more freedom (Schön et al., 1992). The advance in computer capacity and sensor technology (Artmann, 1997) made the feasibility of such equipment a possibility. The reduction in the work load and the possibility of increased labour flexibility and improved social life would be important features for the farmer to consider when investing in an AMS (Mathijs, 2004; Gustafsson, 2004 and Hogeveen et al., 2004).

[1] In this thesis the term Automatic Milking Unit (AMU) is used for the milking stall.

Another reason for investing in an AMS is the fact that cows can produce more milk if the milking frequency is increased (Hillerton and Winter, 1992). Cows milked in an AMS are milked on average more than 2.5 times per day, as shown in Table 1, although there are marked differences in milking frequency between farms having an AMS.

Table 1. Number of milkings per cow and day in different types of milking stalls using an AMS.

No. milking events per cow and day	Type of milking stall	No. dairy farms studied	Reference
2.6 - 3.0	Single milking stall	5 dairy farms	Artmann, 2004.
2.7 - 2.9	Single milking stall	24 dairy farms	van 't Land et al. 2000.
2.1 - 2.8	Multi milking stall	5 dairy farms	Artmann and Bohlsen, 2000.
1.7 - 2.6	Single milking stall	6 dairy farms	Umeland, 2003.
2.2 - 2.6	Single milking stall	2 research dairy farms[2]	Gustafsson, 2004.
2.4 - 2.6	Single milking stall	6 dairy farms	Morita et al. 2004.

New situations and questions to be solved as a result of the introduction of the AMS

The first studies to determine how cows would behave in an "AMS" were carried out under simulated conditions (Rossing et al., 1985; Rabold, 1986; Ipema et al., 1988; Ketelaar-de Lauwere et al., 1998 and Winter, 1993). Once the main technical problems had been solved, the first working prototypes could be used to study cows under more realistic automatic milking conditions (Winter, 1993 and Prescott, 1995). From a behavioural point of view, two questions which needed to be answered were:

A) How could cows be motivated to visit the AMU frequently?
B) How did cows behave in the milking stall and its surroundings?

Cows are willing to visit an AMU if feed concentrate is dispensed there (Devir et al., 1993 and Prescott et al., 1998b). It appears that even playing music has a stimulatory effect on the behavioural readiness of cows to access the AMU (Uetake et al., 1997). One method to get the cows in the AMU is to offer them feed, compulsory passing of the AMU, or at least passing of the selection unit. This has been achieved by installing one-way gates at strategic points in the cowshed (Artmann, 1992; Dück, 1992 and Prescott et al., 1998a). Although one-way gates (forced cow traffic) may improve the frequency of visits to the AMU (Ketelaar-de Lauwere et al., 1998), this restricts the cows' freedom (Metz-Stefanowska et al., 1993) and may therefore be questionable with respect to welfare. Cows kept under a forced cow traffic situation spend less time at the feeding fence than do cows kept in free traffic situations (no one-way gates), according to Jagtenberg et al. (1997), and the cows spend more time waiting in front of the AMU (Hogeveen et al., 1998a). Recent studies suggest that semi-forced cow traffic (one part of the feeding table is freely available) better exploits the AMS's capacity, and that it is better suited for cow behaviour, in comparison to forced cow traffic (Hermans et al., 2003). They

[2] Different hardware (AMS) and breeds between farms.

have found that cows in a semi-forced situation ate for a longer period of time and spent less time standing in the cubicles.

The cow behaviour in the AMU and in the Waiting Area (WA) in front of it has also been studied. Here, distinctions must be made according to whether a selection system is used or not, and whether the system has a single milking stall or a multi milking stall robot. Selection systems are used to separate cows without milking permission from cows that should be milked. Thus, only cows that are due for milking are allowed access to the AMU. Cows that should not be milked are directed back to the cowshed without passing the AMU. Otherwise, cows that should not be milked will occupy the AMU without justification, which constrains the capacity, especially in multi stall units (Ketelaar-de Lauwere, 1992; Ketelaar-de Lauwere and Benders, 1994). The selection unit can be located at the front of the AMU or at the entrance of the WA in front of the AMU. However, the selection unit in itself also influences the capacity of the AMS. Some cows do not leave the selection unit directly if they know they will be divereted back to the herd without a visit to the AMU (Metz-Stefanowska et al., 1993). For this reason, the selection unit can be equipped with mechanical pushers that push out the cows that are reluctant to leave (Devir et al., 1996). A similar system for pushing out reluctant cows can be installed in the AMU (Devir et al., 1996). Attempts have been made to design selection units that select cows in the corridor of the selection unit, during walking (Stefanowska et al., 1999b), or to select cows when they are in the AMU (Ipema et al., 1997 and Stefanowska et al., 1999a).

A single milking stall provides a more compact solution than a multi milking stall. The distance between the entrance and the exit in a single milking stall is about 4.0 m (Insentec's Galaxy, Lely's Astronaut, Fullwood Merlin and DeLaval VMS[3]). For multi milking stalls, this distance is much higher, i.e., 13.5 m for the AMS Liberty[4]. This distance can even be more than 25 m (Westfalia Leonardo[5], with one preparation stall for teat cleaning, four milking stalls and pre- and post-milking selection units). This means that the time that cows spend in a mulitbox system will be much longer than in a single box system, provided that the walking speed in both systems is not affected by size.

The capacity of an AMS depends both on the technical and on the biological factors. The technical factors include first of all how many hours per day the AMU is available for milking (excluding cleaning and necessary service). When available for the cows, the capacity of the AMS depends on: entrance and exit times, and how fast the robot can clean the teats and attach the teat cups. Biological factors affecting the capacity are, for instance, total milk yield per milking and milk flow. Assuming 22 h availability per day, a total time for routines in the milk stall of 1.6 min, and a true milking time of 5.6 min per cow, the AMS theoretically can perform 183 milkings per day. A study by Sällvik et al. (2003) showed that in practise 112 to 154 milkings per day, or on average 70% of maximal milking capacity, was achieved. The same relationship between theory and practise was found regarding the amount of milk obtained per AMU and day, where 2,100 kg milk could be attained, as compared to 1,470 kg on average, although the best AMS-farm reached 1,880 kg/day.

[3] Galaxy Insentec, Het Noord, The Netherlands; Astronaut, Lely Industries NV, Maasland, The Netherlands; Merlin Fullwood, Ellesmere, England; VMS, DeLaval, Södertälje, Sweden.
[4] Prolion Holding NV, Vijfhuizen, The Netherlands.
[5] WestfaliaSurge, Oelde, Germany.

New Technique Testing of milking robots in Sweden

In Sweden, matters regarding animal protection and welfare are regulated at three levels. The Animal Welfare Act is passed by the Parliament. The Animal Welfare Ordinances are decided at the Government ministerial level, and the Animal Welfare Regulations are established by the Swedish Board of Agriculture (SJV). Because of the negative effects on animal health and deterences to natural behaviour (welfare issue) which were imposed by the introduction of new technologies and systems for rearing animals during the 60's and 70's, the veterinarians, the people involved in animal welfare movements and the official authorities wanted these type of problems to be minimised in future animal production systems. In order to achieve this, Articles 7 and 8 of the Animal Welfare Ordinances were implemented in 1988 (Swedish Board of Agriculture, 1998), as follows:

> *New technical systems and new technical equipment for animal housing shall have been approved from the point of view of animal health and protection before taking into use.*

Article 8 states*:*

> *Matters on approval of new technique are considered by the Swedish Board of Agriculture.*

Procedure of the New Technique Test

The procedure to conduct a "New Technique Test" (NTT) can be illustrated by the first test of a milking robot in Sweden, The Lely Astronaut [6]. When Lely Sverige AB, wanted to market their milking robot the "Astronaut" in 1997, the SJV was contacted. SJV decided that the technique should be studied in practise before an approval could be given. There are three categories of preliminary investigations that can be carried out before accepting the usage of new technology in agriculture:
<u>New Technique Test Category I:</u> the decision by SJV is based only on received documents.
<u>New Technique Test Category II:</u> a minor investigation (literature and other references), assisted by practical studies under standard farm conditions when necessary.
<u>New Technique Test Category III:</u> a field trial(s) must be undertaken.
And SJV determines which category of testing would be necessary to evaluate the proposed technology.

The Department of Agricultural Biosystems and Technology (JBT), Swedish University of Agriculture Sciences, Alnarp, received the assignment from Lely Sweden AB to carry through the NTT, which had been assigned to Category III. JBT, SJV and Lely Sweden AB together developed a research plan for testing the milking robot under Swedish conditions. The research plan included those farms in Sweden to which a Astronaut had been sold (these farms had received exemption, so that the NTT could be carried out).

[6] Lely Sverige AB, Nyköping, Sweden.

In the decision by the SJV to approve the application, the SJV gave under the heading "other information", the following specific points to be included in the testing:
1. Animal health.
2. Udder health.
3. Animal behaviour.
4. Animal traffic.
5. Risks and limitations of the technique.
6. Possibility of monitoring and inspecting the animals.

The aim of the New Technique Test

The aim of the NTT is to provide SJV with an opinion about to what extent the tested milking robot, possibly with some restrictions or conditions, could be approved with respect to animal welfare and health considerations for usage in Sweden. SJV makes their judgement based on the report, and eventually with more or less informal contacts with organisations representing animal protection and welfare.

What is included in the Swedish New Technique Test of milking robots?

As noted above, the NTT as required by the SJV was only concerned with animal welfare and animal health. The NTT did not include an evaluation of the milk quality or fulfilment of hygienic regulations, e.g., according to the EU milk directive. Therefore, the following questions to be answered with regards to the system were included in the research plan:
1. Effect on animal health – incidence of mastitis.
2. Effect on teat tip status.
3. Effect on somatic cell count in bulk milk (an indirect measure of udder health status).
4. Analyses of the system's ability to detect and notify the farmer about an animal with mastitis or other diseases or infections which need treatment or special care.
5. Effect on animal behaviour and stress by the system (cow traffic, waiting time in front of the robot, aggressions).
6. Identifying details in the system which deter natural behaviour or stress the animals.
7. Adequacy of the manuals and personal support (advisory service) to the farmers.

The points 1-3 were analysed by comparing conditions before, during and after the test period. Point 4 was analysed by reconstructing the "warning lists" 0 – 10 days before a specific cow had been treated for clinical mastitis. Points 5 -6 were judged by visual observations of behaviour. Point 7 was evaluated by studying the manuals and questioning the farmers.

Beside carrying out the NTT for the Lely Astronaut (Oostra and Sällvik, 1998), JBT has been responsible for three more NTTs regarding AMSs: the NTT of the Fullwood Merlin [7], a Category III test (Oostra and Sällvik, 2000b); the NTT of the Leonardo Westfalia [8], a Category III test (Oostra and Sällvik, 2001); and a Category II test of the Prolion AMS

[7] Merlin Fullwood, Ellesmere, England
[8] WestfaliaSurge, Oelde, Germany

Liberty [9] (Sällvik and Sällvik, 2002). Papers I and II in the present thesis are a direct consequence of the NTT. In II an alternative to using the electrical movement inductor banned by SJV is described. Directly after the introduction of the AMS in Sweden, the studies of Ketelaar-de Lauwere were (erroneously) quoted, for instance, to point out that cows with a low rank had a considerably harder time in an AMS then did higher-ranking cows (Ketelaar-de Lauwere et al., 1996), and that grazing was very problematic when combined with automatic milking (Ketelaar-de Lauwere et al., 1999b and Ketelaar-de Lauwere et al., 2000). A possible method of relieving the situation for cows using an AMS might be to apply a frequent feeding regime (I).

Structure of the thesis

This thesis can be divided into two main parts; the first part discusses management tools/procedures to influence cow traffic, and the second part discusses technical tools to detect cows with deviating behaviour in animals using an AMS. The areas studied in this thesis are indicated in Table 2.

Table 2. Short description of papers referred to in this thesis.

Paper	General area studied	Method	Data used from
I	Cow traffic around AMU and utilization of cowshed facilities	Change feeding frequency	AMS, video observations, direct observations
II	Cow traffic around the AMU	Conditioned reinforcement	AMS, video observations
III	Identification and location of cows	Description of an optical real time location system (ORTLS)	
IV	Identification and location of cows	Application and evaluation of an Optical Real Time Location System (ORTLS)	ORTLS
V	Automatic detection of locomotion disabilities	Application and evaluation of a method to assess locomotion	Scale measurement and video observations

[9] Prolion Holding NV, Vijfhuizen, The Netherlands.

Aims of the thesis

The aims of the thesis were;

- To study the effect of management procedures on cow behaviour and their consequences in an AMS.
- To study if technical tools can be used for behavioural studies and for detecting particular deviating patterns in dairy cows.

The specific aims as follows:

- How does an increased feeding frequency from two times a day to six times a day affect cow waiting time, automatic milking stall visiting pattern and other activities in the cowshed? (I).

- Can conditioned stimuli be used as a mean to make dairy cows to leave an AMU faster in order to increase the system capacity? (II).

- To describe and evaluate a system for the automatic identification and location of individual dairy cows in loose housing system. (III and IV).

- To describe and evaluate a system that automatically can detect dairy cows with locomotion disabilities (V).

Management procedures

As noted previously, the introduction of the AMS has led to new aspects and problems in the management of dairy cattle. One of the aims of this thesis was to determine how altering some of the management procedures could optimise the functioning of the system without having negative effects on the cows.

Feeding frequency

In conventional milking systems, all the cows are milked twice or three times daily, although not simultaneously, but still within a very short time frame. In an AMS, this is not possible due to the limited capacity of the system. Hypothetically, when herd synchronization is expressed to the fullest, the cows would move as one group through the AMS. They would all eat at the same time, they would all lie down at the same time and they would all visit the AMU at the same time. This is not possible under practical conditions in production herds. The cows need to de-synchronize their behaviour when milked in an AMS. This can be achieved if the cows form sub-groups, or if they visit the AMU independently of each other. However, in groups, the activity of one cow can stimulate the other cows to perform the same activity (Ketelaar-de Lauwere et al., 1999b and Metz and Mekking, 1978). A possible means of stimulating cows to express a sub-group like behaviour may be to increase the feeding frequency. When fresh forage is provided on a regular basis cows may also show a more individual activity pattern, i.e., they visit the AMU by themselves and then go to the feeding fence by themselves.

Materials and Methods (I)

In Paper I, the forage feeding frequency for 40 dairy cows, milked in an AMS, was altered from two feedings per day (Period A) to six feedings day (Period B). Period A was preceded by a habituation period of 12 days and Period B was preceded by a habituation period of 28 days. Data was collected by using information from the AMS, direct observations at the feeding fence after forage supply, and video registration.

Results, Discussion and Conclusion (I)

The results showed that the time spent in the WA in front of the AMU was significantly shorter when the cows were given forage six times a day in comparison to two feedings per day (351 sec and 755 sec, respectively). The Feeding Activity Factor (FAF), a factor describing the number of times a cow was observed at the feeding fence 10 min after forage feeding, was also higher when forage was given six times daily, indicating that the cows had more direct access to fresh forage under those conditions. The cowshed facility utilization was also studied. The cowshed facilities (floor and cubicles) in the WA were more evenly used when the cows were given the higher feeding frequency. No significant differences were found with respect to the utilization of the cowshed facilities in the rest of the building, although the utilization of the feeding fence tended to be more even when the cows were fed six times in comparison to twice daily.

It was concluded that the waiting time in front of an AMU would be significantly reduced if the forage feeding frequency were increased from two to six times per day. However, the number of visits to the AMU was not affected by the feeding frequency. It was concluded that an increased feeding frequency also affected positively the utilization of the studied cowshed facilities, such as the occupation of the feeding fence, cubicles, and feed alley, respectively.

Conditioned reinforcement

The first milking robots were installed in Sweden in 1998, and were equipped with an electrical movement inductor to encourage the cow to leave the AMU. After the AMU exit gate had opened, the cow had 10 sec to leave before she received a series of weak electrical shocks. In the NTT, the cows’ reaction to this electrical inductor was investigated, and it was found that 90-95% of the cows left the AMU before the first electrical shock was given (Oostra and Sällvik, 1998), (Figure 1).

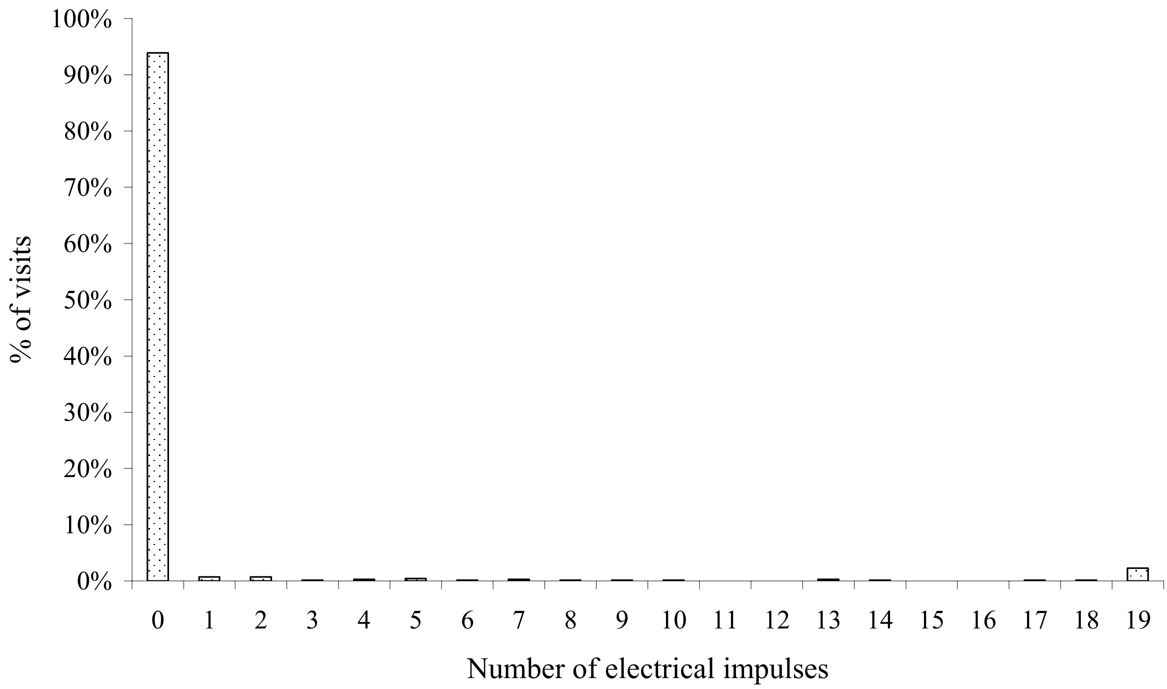

Figure 1. Number of electrical pulses from the movement inductor required to make dairy cows leave the AMU (after Oostra and Sällvik, 1998).

The SJV disapproved of the use of the electrical movement inductor, and stated that its removal was a condition for the approval of the milking robot – and its use in Sweden was banned. This movement inductor is still in use outside of Sweden (Hopster et al., 2002). The reason for using a "movement inductor" is that cows frequently must be encouraged to leave the AMU (Allen et al., 1992 and Metz-Stefanowska et al., 1992). Winter (1993) stated that "C*learly encouraging cows to leave the system will be as important as encouraging re-entry*".

In Table 3 the entrance and exit times for the cows are shown from time studies of two different brands of single stall milking robots, A and B, (Sällvik et al., 2003). The entrance time is about 10 seconds for all makes. However, the exit times differ substantially between the two makes.

Table 3. Moment times of the cows for Entrance, Preparation and Exit in two brands of single stall milking robots (Sällvik, et al., 2003).

Farm	AMS brand	Entrance time (sec)	Preparation time (sec)	Exit time (sec)
1	A	8	66	11
2	A	10	76	17
3	A	10	77	15
4	B	8	63	52
5	B	9	64	20
6	B	8	45	95
mean		9	67	35

On Farms 1, 2, 3 and 5 (Table 3), the cows all have exit times between 11-20 sec, which indicates that she leaves the AMU more or less immediately after the exit gate has opened (Table 3). On Farms 4 and 6, however, much higher exit times are found. Brand A has no other means to "push" the milked cow out, other than by opening the entrance gate when the cow in the AMU is finished, meaning that the entering cow has to push the previous cow out if she is not going voluntarily. Brand B does not open the entrance gate until the AMU is empty.

Oostra and Sällvik (2000a and b) found that in 5-10% of the AMU visits, some cows are still in the AMU 2 min after the exit gate opened, as shown in Figure 2. In this AMU, no movement inductor had been installed, although the feeding trough was made inaccessible when the exit gate opened.

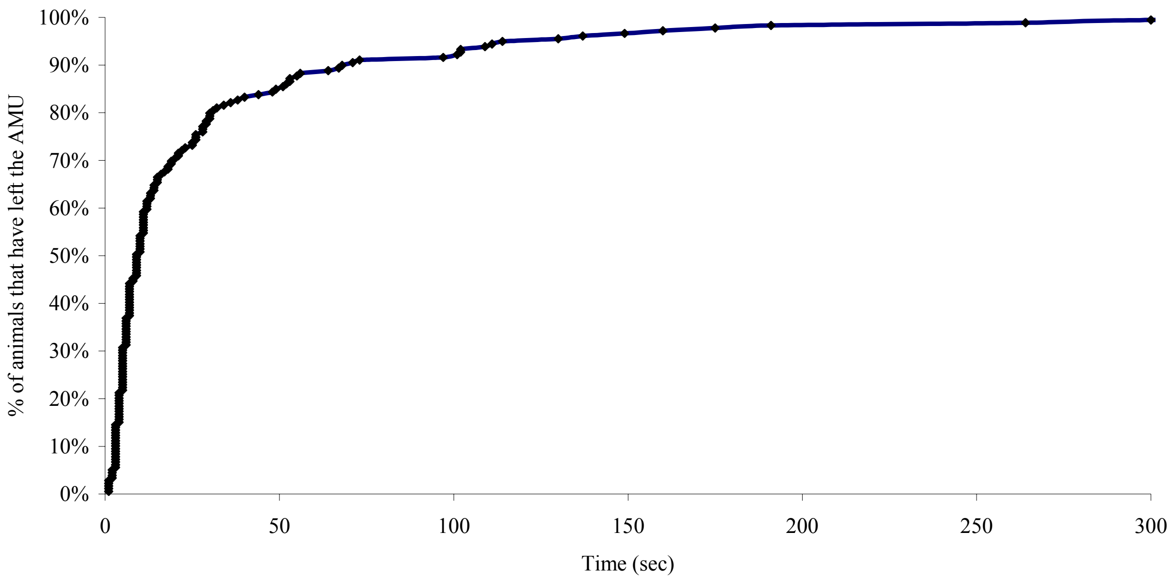

Figure 2. Time needed for cows to leave an AMU where no reinforcement was used (after Oostra and Sällvik, 2000a).

It is important that the cows do not have negative experiences in the AMU to such extent that negative associations are invoked, making them reluctant to enter the unit again. Providing a clear discriminative stimulus signalling the onset of a negative reinforcement should, according to learning theory, minimise the risk of the cows associating the entire AMU with the aversive stimulus (Domjan and Burkhard, 1986).

Materials and Methods (II)

The purpose of this study was to determine the influence of different types of light Conditioned Reinforcements (CR), to make the dairy cows leave the AMU more rapidly. The cows originated from two different groups, one group of primiparous cows (A_0) and one group of multiparous cows (B_0). Both groups were milked in an AMU situated in the same building. From each group, cows that were 250 days in lactation or less and had an average AMU exit time exceeding 10 sec were selected. Both selected groups were divided into two sub-groups, A_1, A_2, B_1 and B_2. The cows in A_1 and B_1 were subjected to an acoustic signal, which was a Neutral Stimuli (NS) indicating that the AMU exit gate had been open for 10 sec. The cows in A_2 were subjected to an acoustic signal (NS) and a moving flexible tube rubbing their sides (CR), and the cows in B_2 were subjected an acoustic signal (NS) and a moving flexible tube or a bright flashing light (CR). The introduction effects and long term effects of the NS and CR were studied using data from the AMS and video observations.

Results, Discussion and Conclusion (II)

The exit times for primiparous cows without using a CR were between 109 and 125 sec. The exit time for these cows decreased between 93 and 97 sec when a NS or CR was used. The effect of the CR did not diminish, that is, there was a long-term effect. The acoustic signal alone (NS) was as effective as the acoustic signal + moving tube in these cows.

Multiparous cows had an exit time without the use of negative reinforcement between 178 and 193 sec. Cows subjected to an acoustic signal + moving tube or light (CR) decreased their exit times by 168 sec, and the effect did not diminish over time. Those subjected to the acoustic signal only (NS) showed a comparable decrease in exit time directly after the introduction of the treatment. However, no long-term effect could be found when only the acoustic signal was used.

It was concluded that it can take on average up to 3 min for a cow to leave the AMU after milking. The time needed to leave the AMU could be reduced substantially by using Conditioned Stimuli[10] with a light negative reinforcement. It appears that the reinforcement used in the present study did not affect the cows negatively, since the time needed for the animals to enter the AMU was not changed. There would be time available for 10-15 extra milkings per day under these conditions if a light Conditioned Reinforcement system were installed.

Technical tools

Aids for behavioural studies

The system described in III and IV is intended for the automatic and almost continuous determination of an individual cow's location in the cowshed throughout the day. The purpose of such a system is to study the spatial behaviour of individual cows in a full commercial sized group, and obtain information that could influence future cowshed design and feeding practises.

[10] As a historical note, it should be remembered that the lead or highest ranking cow was often belled, and herdsman have been known to blow horns or make some other type of acoustical signal indicating it was time to leave the grazing area.

Spin-off possibilities

The information gathered by the AMS's management system and presented to the farmer is overwhelming, yet at the same time limited. It is overwhelming in the sense that the farmer is confronted with information about milk yield, milking interval, milk conductivity, milk time, dead milk time, milk temperature, etc. The information is limited in the sense that only data associated with milk or milking activities are presented. A cow spends about half an hour per day in the AMU, three visits lasting for about 10 min each. No information is available with respect to her whereabouts or activities during the remaining twenty-three and a half hours, except when visiting automatic feeders where visiting registration is used. This can provide some additional information. A system that automatically can track the individual cow continuously will supply additional important information. Deviating health status (e.g., locomotion problems) can be detected. Tracking cows with mastitis and thus being able to locate contaminated cubicles can be another advantage. In the search for better cowshed designs to improve the regularity of the cows visiting the AMU, an automatic and continuous tracking of individual cows will be a large step forward.

Another, more mechanistic, approach would be to try to control the AMU visiting behaviour of the individual cow, a situation where the herd synchronisation has completely disappeared. Previous attempts have been made to try to "control" the behaviour of cows (Hopster and Wierenga, 1988 and Wierenga and Hopster, 1989), by affecting the timing of visits of dairy cows to a concentrate feeder by means of an acoustic signal. Their results showed that the response was quite acceptable, although it was less effective when the cow had to walk some distance, in comparison to when she was nearby the feeder. The response was also very low when the cow was lying down when the signal was received. The next logical step would be to only beep up cows that are entitled to concentrate, and at the same time are in the vicinity of the concentrate feeder. This could only be done if the location of the individual cows were known.

Transferring this idea to AMS-conditions: cows needed to be milked and in the vicinity of the AMU could be stimulated to visit the AMU with such a system. Wredle et al. (2004) used an acoustic signal in a cow-calling experiment in an AMS environment. Their preliminary results showed that cows did approach the AMU more often following an acoustic signal, in comparison to the control period (no signal). However, the response was not as clear when it came to the cows actually entering the AMU. Some of the factors that might explain those observations are too small a reinforcement given (size of concentrate portion), and the cow having to wait at the front of the AMU after a positive response to the acoustic signal (queuing problems). It has been noted that cows in an AMS hesitated to act on their own, but preferred to be accompanied (Ketelaar-de Lauwere et al., 1999b and Ketelaar-de Lauwere et al., 2000), which would be typical of the herd mentality. It would be interesting to know if cows form behavioural sub-groups, within the herd, and if so, did these behavioural sub-groups coincide with their production level, and desired milking interval? In either case, using the above outlined "cow-calling" only when the location of the cow(s) in the AMS is "OK" could be so that cows in the same sub-group could be called at the same time. However, it would not be certain that such a system would be desirable from the cow's point of view, even if it were technically possible. *To expect them to act in sequence or line, one after the other is an overly mechanistic concept for such a social species* (freely after Hurnik, 1992), and certainly would affect cow welfare, probably negatively.

Material and Methods (III and IV)

In III and IV, an Optical Real Time Location System, ORTLS, is described and evaluated. The system consists, in principal, of the following parts, a collar with a light emitting diode (LED), Radio Frequency Synchronisation Unit (RFSU), which synchronises the light emitting diodes, video cameras and a computer with the appropriate software (VPS), as shown in Figure 3.

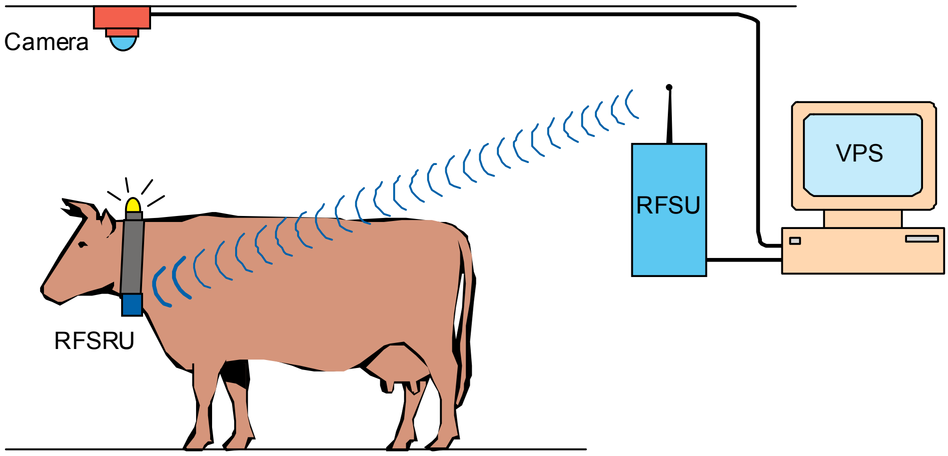

Figure 3. Principal parts of an ORTLS (Kim Gutekunst).

The system functions as follows: Each cow carries a special collar equipped with a Light Emitting Diode (LED), that flashes once per min. The LEDs are synchronised by the Radio Frequency Synchronisation Unit (RFSU), which sends a signal that is captured by the Radio Frequency Synchronisation Receiving Unit (RFSRU). The light flashes are captured by video cameras. The video signal from the cameras is "translated" by the VPS into x- and y-positions and is stored, together with the actual cow ID and time. A group of up to 60 cows can be followed with this equipment.

Results, Discussion and Conclusions (III and IV)

The results of the studies showed that the system tested by a hand held LED gave accuracy of 0.39 (± 0.18) m. However, when the system was used with cows, the system detection rate varied considerably. The highest detection rate was found in the feeding area (90%), and the lowest was found in the lying area (10%). The large differences in detection rate between areas might be explained by the fact that the cameras that covered the eating area were directly above the feeding fence, whereas those covering the lying area were not located directly above the cubicles. This was not possible due to the roof construction. It was concluded that the cameras should preferably be installed above the areas where the cows tended to bend their necks downward, i.e., the cameras should be installed directly above the feeding table and above the cubicles. It was also noted that the collars rotated a little, so that the LEDs ended up on either side of the cow's neck, frequently breaking the line of sight to the cameras.

Bollhalder et al. (2002) and Kaufmann et al. (2003) reported that their positioning system using optics as well has a 98% detection rate. However, problems related to the transition zones (zones between the cameras) and problems with direct solar radiation has resulted in that research with optical systems at the Swiss Federal Research Station for Agricultural Economics and Engineering, Tänikon, Switzerland has been abandoned (Bollhalder, H., pers. com., 2004). Instead, research has been continued to determine cow location in the cowshed using a system based on radio wave technology. The problems with the radio waves being reflected by metal structures in the building have been solved[11] by using a sufficient number of receiving antennas and a corresponding real-time-statistics algorithm (Bollhalder, H., pers. com., 2004).

It was concluded that the ORTLS in its present state cannot be used for tracking cows adequately. The system needs to be improved, because the detection rate was too low and it varied between areas in the cowshed.

Detection of locomotion problems

The efficient function of an AMS is dependent on well functioning cow traffic. In an AMS, the cows have to voluntarily present themselves on a regular basis several times per day, depending upon the need to milk. The number of desirable visits is set by the farmer/herd manager and reflects the desired milk yield and the needs of the cow. Cows with a high milk yield require more milking visits than cows with a lower milk yield. Cows that do not show up in time at the AMU (too long milk intervals) must be manually brought to the AMU. This means that the farmer/herd manager must go in to the cowshed, find the particular cow (or cows, if more than one has to be fetched) and bring her/them to the AMU. This activity does not please the farmer, and it is in fact not compatible with the idea of automatic milking. A factor that may affect the milking interval is lameness. Grove et al. (2004) have found that the average time between milkings increased when the locomotion score increased (high locomotion score means abnormal locomotion). In other words, the pain of walking offset the need to be milked. It has been shown that cow locomotion does not change when farms convert from conventional to automated milking (Dearing and Hillerton, 2004 and Vosika et al., 2004). However, Vosika et al. (2004) have pointed out that in their study the long-term effects on locomotion might not be revealed since a relatively high number of cows were replaced for other reasons than locomotion-related problems.

Material and Methods (V)

In Paper V a method is described that combines the evaluation of locomotion scores of dairy cows with an evaluation of the weight distribution between the legs. The objective of this study was to evaluate a method that could automatically detect cows with deviating locomotion. In the study, thirty-two dairy cows were given a Locomotion Score (LS) according to a method described by Zimmerman (2001). A low LS indicated a healthy cow with no visible locomotion disabilities, and a high LS indicated a cow with locomotion problems. The cows were also subjected to standing on a scale, which measured the Ground Reaction Force (GRF) for each leg. From the GRF, the Average Ground Reaction Force (AGRF) was calculated for each cow. The cows were subjected to the scale and given a LS in

[11] Abatec, 4844 Regau, Austria, www.abatec-ag.com.

four trials, which were carried out directly after each other, for each cow. The four AGRFs obtained for a cow were combined into three different Symmetry Factors (SF), $SF_{front\text{-}hind}$, $SF_{ipsilateral}$, $SF_{contralateral}$ according to the following equations (explanation of factors given in V):

$$SF_{front-hind} = \frac{\left|(AGRF_{lf} + AGRF_{rf}) - (AGRF_{lh} + AGRF_{rh})\right|}{(AGRF_{lf} + AGRF_{rf}) + (AGRF_{lh} + AGRF_{lh})}$$

$$SF_{ipsilateral} = \frac{\left|(AGRF_{lf} + AGRF_{lh}) - (AGRF_{rf} + AGRF_{rh})\right|}{(AGRF_{lf} + AGRF_{lh}) + (AGRF_{rf} + AGRF_{rh})}$$

and

$$SF_{contralateral} = \frac{\left|(AGRF_{lf} + AGRF_{rh}) - (AGRF_{rf} + AGRF_{lh})\right|}{(AGRF_{lf} + AGRF_{rh}) + (AGRF_{rf} + AGRF_{lh})}$$

The relationship between the response variable (LS) and the explanatory variable (SF) was determined using logistic regression. For each response variable (LS), a logistic model was developed expressing the probability as a function of the explanatory variable (SF), according to the equation below.

$$P_1 = \frac{e^{\alpha_1 + \beta_1 * SF}}{1 + e^{\alpha_1 + \beta_1 * SF}}$$

Results, discussion and conclusions (V)

The probability distribution for LS is shown for $SF_{contralateral}$, in Figure 4. The figure shows that for $SF_{contralateral}$-values smaller then 0.3, more then one LS could be given. For instance, if $SF_{contralateral}$ was equal to 0.05, the probability that a score of 2.5 was given was 0.5 (arrows in Figure 4).

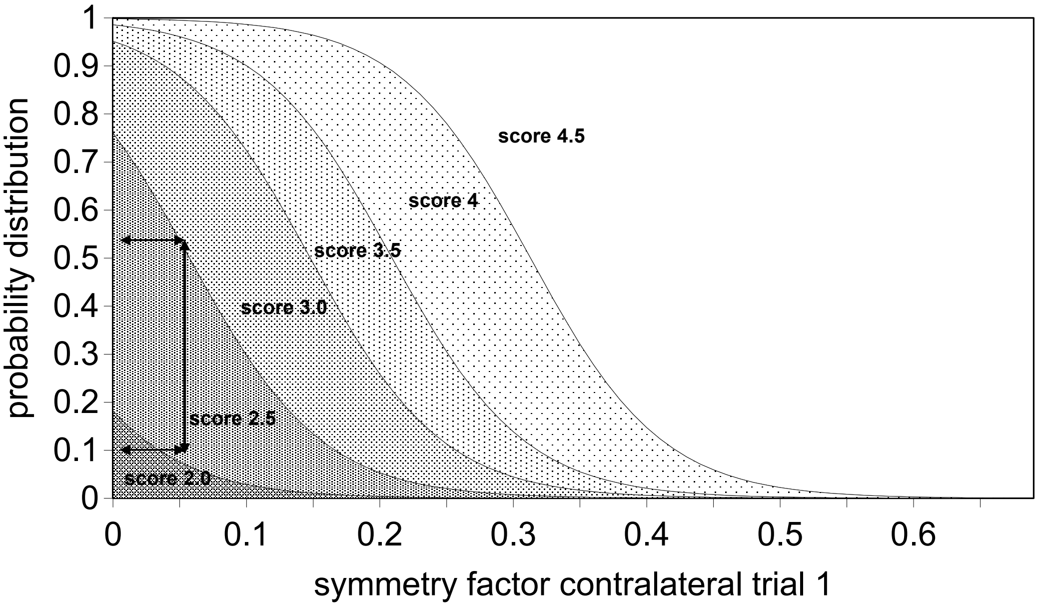

Figure 4. The probability distribution of Locomotion Score (LS) from the first trial as a function of the Symmetry Factor contralateral, ($SF_{contralateral}$).

Similar figures were found for the other two SF. There was no effect of trial number. It was concluded that the method in its present form could not be used to automatically detect a cow with a deviating locomotion. The method must produce similar results to that shown in Figure 5 in order to be acceptable (simulated results), since it more accurately reflects the true locomotion status of the animals.

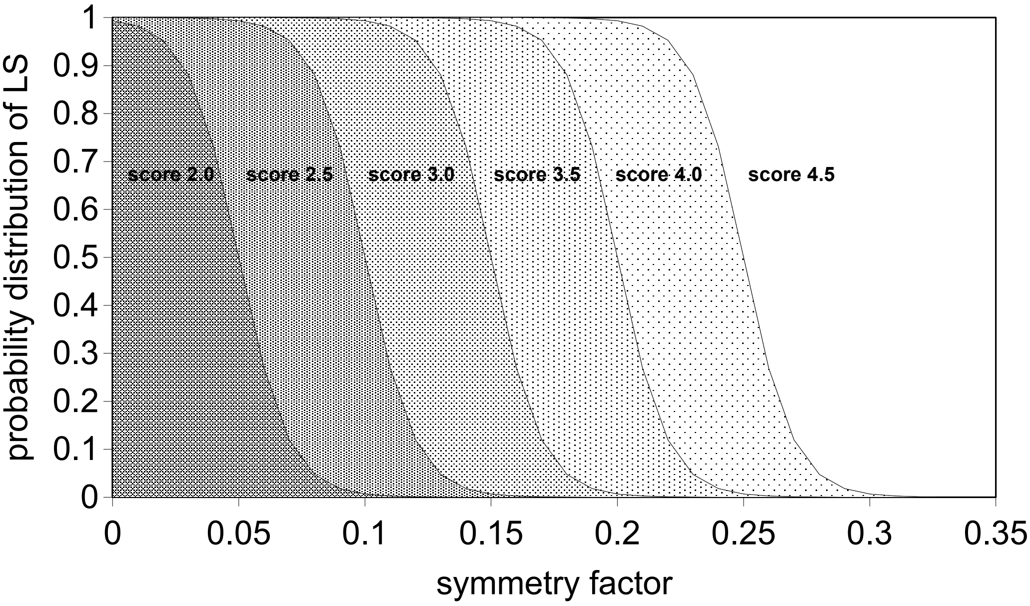

Figure 5. Fictive probability distribution of locomotion score as a function of a Symmetry Factor (simulated data).

An explanation for the poor results may be:

- The cow had a more interesting view to her left than to her right, and as a result the data may be biased (cow's head held more often to the left than to the right, thus changing her weight distribution on the legs).
- Two different activities were compared: walking (LS) is compared with standing (SF).
- The cows were only permitted a short habituation period, which might have prevented them from standing undisturbed.
- The cows were pushed back if they did not stand properly on the scale, that is, they were forced to stand in a specific, uncomfortable position.
- Lameness did not always appear to be related with a reduction in Maximum Vertical Force (Scott, 1989).

Similar studies were carried out by Rajkondawar et al. (2002a) and Ahokas et al. (2004), and Rajkondawar et al. (2002b) demonstrated that their Reaction Force Detection system (RFD) could objectively recognize lame animals and identify the affected limb. One of the differences between the system described by Rajkondawar et al. (2002b) and the method described in V was that their RFD was based on a walk-through system (Rajkondawar et al., 2000), whereas in V, the cows were standing still. The study of Ahokas et al. (2004) was carried out over a longer period (more then 50 days) than in V. They demonstrated that the weight distribution changed for cows over this period.

It was concluded that the tested method (V) for the automatic detection of cows with a deviating locomotion did not work satisfactorily.

General considerations

Research methodology

The studies reported in Paper I and II were carried out on the same commercial farm. The use of commercial farms as a host for behavioural experiments was not unproblematic. The experiment had a very low priority for the farmer/herd manager, even if he was interested in the experiment as such. His main concern was to maintain normal daily management routines. For the experiment with an altered feeding regime (I) it appeared as if a large difference in the daily routine was involved, since the feeding regime was altered substantially. However, it did not change the herd manager's routines at all. He kept feeding the animals twice per day. The extra four feedings during Period 2 in I, were carried out by the researcher. The herd manager was also anxious that the experiments could affect cow traffic and milk production negatively. The changes made in the cowshed (construction of waiting area) before the alteration in the feeding regime did cause some concern for the herd manager, but the advantages of having a waiting area outweighed the possible negative effects that this might have had on cow traffic at the beginning of the study. The installation of the bells, plastic tubes and lamp (II) was also regarded as being an improvement, since the herd manager considered that too many cows remained for too long a time in the AMU.

Variations in herd size

It is very difficult to maintain a constant number of cows and the same individual cows in a production herd studied over longer experimental periods. This is not only true for experiments carried out on commercial farms, but it is also valid for studies carried out on experimental farms. Varying herd size during field trials have been reported by (Hermans et al., 2003; Ketelaar-de Lauwere et al., 1998; Stefanowska et al., 1999b and Wierenga and Hopster, 1991). In the studies described in I and II, cows were removed from the herd and other cows were added during the course of the studies, although the cows being studied remained the same. It is difficult to assess to what extent this change of cows affected the dynamics in the herd and how this is reflected in the results. The effect may not have been severe since most of the animals that were added had previously been removed because they had dried off. They returned to their groups shortly after calving. Besides, once learned, relationships between cows persist for a long time (Beilharz and Zeeb, 1982).

Habituation

In the literature, the time allowed for the cows to habituate in behavioural studies varies substantially. Uetake et al. (1997) assessed the effect of music on the voluntary approach of cows in an AMS. The 19 experimental cows were habituated to the AMS for 10 days. Milking was carried out twice daily. After the AMS-habituation period, the cows were habituated to the music. The music started to play when milking started. This habituation period lasted for 69 days. The observation period lasted for 20 days.

A habituation period of two weeks followed by an observation period of one week was used by Hogeveen et al. (1998b). They studied the effect of free and forced cow traffic. A similar experimental design was used by Hermans et al. (2003), when they studied the effects of two routing situations (forced and semi-forced traffic) on the behaviour and performance of cows in an AMS. The habituation period lasted two weeks and the observation period lasted 1 week, of which 3 days were used for the data analysis.

A habituation period of one week and an observation period of two weeks were used by Ketelaar-de Lauwere et al. (1999a) when they studied the effects of routing situations on the behaviour and performance of cows in an AMS.

In I of this thesis, 12 days of habituation were give to accustom the cows to the newly installed waiting area in combination with the twice daily feeding regime that was normally applied. An additional habituation period of 18 days was used to accustom the cows to the feeding regime of six feedings per day. In V the cows were allowed *some time* for habituation before she was required to step onto the scale. It was not enough to simply apply a habituation period that appears to be reasonable or that fits in the experimental time frame. If studies are conducted that require a steady state for the investigated parameter (as was the case in the studies reported on in I and V), this parameter should be continuously measured during the habituation period. The observations could first start when a steady state has been obtained. A steady state situation for a large group of cows would probably require more than two weeks to establish (Hogeveen et al., 1998b).

General Discussion

The results presented in this thesis showed that the waiting times in front of the AMU for cows milked in an AMS could be shortened by increasing the feeding frequency, in this case, of forage. It has been demonstrated that the effects of social status were more pronounced when facilities were more scare (Metz and Mekking, 1978 and Kenwright and Forbes, 1993). Therefore, it would be most important that coveted entities, such as, forage, concentrate and cubicles, are available to the cows, perhaps not in unlimited amounts, but certainly be adequately provided for, in a cowshed containing an AMS. The results of Paper I showed that an increased feeding frequency could provide for such a situation.

Previous studies have shown that cows sometimes remain in the AMU after being milked. Providing a reward after leaving the AMU to make the cow to depart without delay might only shift the problem to the location where the reward is given. Prescott (1995) provided concentrate to the cows directly after they had left the AMU, but it was not clear whether his method would really work in a larger herd. As shown in the thesis (II), using a CR with a preceding NS appeared to be a good method of “reminding” cows to leave the AMU, although the study only extended for three weeks and no “longer” term effects were evaluated. It was distinctly possible that the cows would have become habituated to the CR after a longer period. It was considered that the CR described in II was not particularly severe for the cows. A more distinct CR could perhaps have maintained its effect. The usage of such a CR must under no circumstances have a negative influence on AMU entrance time, visiting pattern or other cow related activities the concerning the AMU. It must also be acceptable to the general public. Another method of minimizing or solving the problem of cows delaying their exit from the automatic milking stall would be to restrict the amount of concentrate, and open the entrance gate to the AMU just a second after the exit gate has opened. The cow waiting outside would be motivated to enter the AMU and would push the slow cow out. It should be noted that an exit stall, allowing the exiting cow a “free way” out from the AMU would then be needed.

In this thesis, two techniques were studied that a) automatically registered the location of individual cows in a loose housing cowshed (III and IV) and b) automatically detected cows with deviating locomotion (V). Unfortunately, due to technical problems neither techniques have reached a sufficient level of reliability and more research is needed. The system developed for the determination of cow location in the cowshed uses optics (Optical Real Time Location System, ORTLS), which at the present level of technology may not be a suitable method. The problems described in IV due to the failure of the LEDs to maintain position on the cows, and the difficulties with the camera location can be solved. However, the system will always suffer from its most essential element, the use of optics. If the line of sight is broken between the camera and the tag, for whatever reason, the system cannot determine the position of the LED, i.e., the cow. Missing values will not really be a problem, provided that these missing values are evenly distributed, in this case, throughout the cowshed. Paper IV showed that this was not the case. Different parts of the cowshed suffered unequally from this defect due partially to its construction. It was not clear if the detection rate of the ORTLS could ever reach a satisfactory level. Perhaps other solutions, such as using radio waves instead, have a higher possibility of reaching sufficient detection rate although this would imply other problems.

Unfortunately, the method for the automatic detection of locomotion disabilities, as described in Paper V, did not reach an acceptable level of accuracy. Problems included the cows not standing on the scale properly, too short a test period, and comparing two different activities (walking and standing). However, other studies have shown that the automatic detection of locomotion disabilities (or lameness) is possible using scales. A functioning system would provide the farmer with very valuable information. Developing hoof or leg problems could be detected early, enabling inspection and treatment at a very early stage.

Conclusions

The conclusions and suggestions for possible improvements for the cows and the herdsman/manager obtained according to the specific aims set for the thesis are:

- Feeding the dairy cows six times per day compared with twice in an AMS has the following advantages:
  - The total waiting time in front of the AMU time decreases, this means that cows due for milking can expect to be milked within a shorter time after arrival at the AMU. It also means that the cows have improved possibilities of expressing their own preferences in choosing activities.
  - The cowshed facilities in the Waiting Area are more evenly utilised
  - The utilization of the feeding fence was more even thus there was less competition for coveted entities, providing for a more optimal situation for the cows to reach their production potential.

- A light conditioned reinforcement can be used to make the cows leave the AMU more rapidly after a successful milking, thus increasing the number of possible milkings per AMU and day, and hence the amount of harvested milk. The reinforcement as described, does not prolong the time for cows to enter the AMU.

- The aim to find a system that could identify and track cows automatically could not be achieved due to the low and uneven detection rate of the method described. The system detection rate of ORTLS must be improved. It could not be used for behavioural studies in its present configuration.

- The aim to find a system that could automatically detect cows with a deviating locomotion could not be reached due to systematic errors in the collected data. The described method using a scale for the automatic detection of cows with deviating locomotion in combination with a locomotion score has a potential if the cows have been habituated to the system, and the data has been collected over a longer period of time.

Areas of future research

When evaluating the effect of a Conditioned Reinforcement (II) only successful milking visits were considered. It would be interesting to know what the effect of light conditioned reinforcement had on the exit time after non-milking visits and failed milking visits.

In II, it was not possible to study if there were any concentrate remaining in the AMU. It would be interesting to determine how concentrate residues in the AMU affected exit time and AMU visiting behaviour of the cows.

In the future, systems for the identification and tracking of animals in real time will be available. When reliable (and affordable) systems for cow identification and tracking are present, a number of questions both for scientific and management purposes can be investigated:

- Do cows move in sub-groups through an AMS?
- Can cows be stimulated to pay a visit to the AMS, if they are in the vicinity?
- Can mastitis better be controlled by tracing the sick animals and by regularly cleaning the contaminated cubicles?
- Is it possible to design key-figures based on location data that will provide the farmer with a tool for finding cows with deviating behaviour?
- Evaluation of floor material by occupancy and walking speed, in other words, perform preference tests more simply and rapidly.
- Evaluate feeding regimes and space allotments at the feeding fence.
- Provide individual feed allotment and conditioned access to specific areas.

Determine if it would save time for the farmer to have each cow carry a tag that can be computer controlled (turn LED on and off). This could be done by having cows that need to be found in the herd have a tag that will remain turned on while the tags on the other cows are turned off. Thus, the cows that need to be found could easily be spotted by their flashing tag.

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